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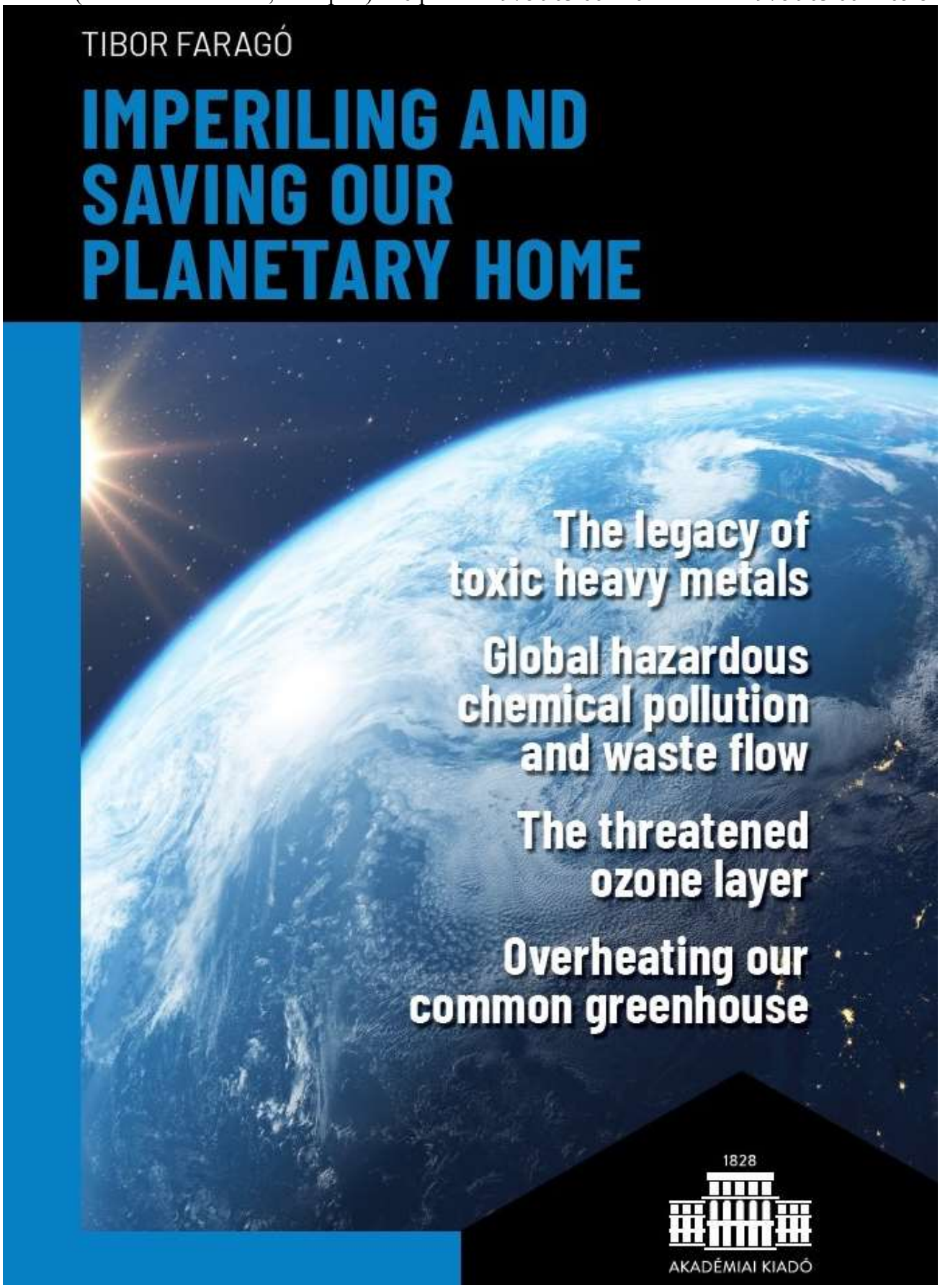

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Tibor Faragó

IMPERILING AND SAVING OUR PLANETARY HOME

THE LEGACY OF TOXIC HEAVY METALS ● GLOBAL HAZARDOUS CHEMICAL ● POLLUTION AND WASTE FLOWS ● THE THREATENED OZONE LAYER ● OVERHEATING OUR COMMON GREENHOUSE

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Our common planetary home is affected by hazardous environmental processes stemming from human activities. These have gradually reached a global scale during the past century, especially concerning the environmental releases of toxic heavy metals, hazardous chemicals, and waste, the atmospheric emissions of ozone-depleting substances, and greenhouse gases. All these are directly or indirectly related to the accelerated utilization of a multitude of natural resources and land use changes, and in the broadest sense, to unsustainable production and consumption patterns. These significantly influence the living conditions of present and future generations. The chapters of this book present the emergence, globalization, and escalation of the above-mentioned environmental processes, the history of the recognition of their unintended harmful impacts, the development of the associated international scientific and political cooperation, and the most essential outcomes of the latter, including multilateral programs and agreements. Following the extensive review and analysis of these processes, key conclusions and lessons are drawn.

* * *

The author of this book has been working on this topic for decades, including through his involvement in the work of several international organizations. He has a detailed understanding not only of the natural laws governing planetary environmental processes (that fundamentally determine the life of human societies) but also of the highly complex regulatory affairs concerning human activities that significantly affect the state of the natural environment. Four human-induced environmental problems are explored in this book – their historical antecedents and current situation – which have become particularly critical on a global scale. I recommend this thought-provoking and readable book to those who are interested in the most important environmental problems of our time and the process of their international management.

László Bozó, academician

This book is an invaluable source document of all the efforts made by international community over the past fifty years to preserve the health of our planet. It could be written only by someone who has closely observed these efforts. It should be compulsory reading for everyone involved in international issues and cooperation concerning environment protection, including representatives of relevant governmental and non-governmental organizations. It might not be an exaggeration to say that officials and experts at the international institutions in this field would also benefit from studying this book, to avoid repeating past mistakes and gain valuable insights from their colleagues' experiences. I commend the author and recommended the publication of this book with professional conviction and sincere pleasure.

Prof. Dr. Sándor Kerekes

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FOREWORD

"*Aerem corrumpere non licet" – The air must not be polluted*. This was a legal order proclaimed by the Roman Senate some two millennia ago. This regulation was born from the realization that unhealthy air pollution, caused by urbanization and the proliferation of workshops producing various consumer goods, had become commonplace. The complexity and spatial extent of this problem have increased significantly, especially since the beginning of the Industrial Revolution. But, as one may realize after reading the book, while our planet's environment is in ever greater danger, saving it is not an impossible mission since – concerning this challenge – our scientific knowledge is growing, and international political cooperation is developing.

The author of this book, Tibor Faragó, has been working on this topic for decades, including through his participation in the work of several international organizations. He has a detailed understanding not only of the natural laws governing planetary environmental processes (that fundamentally determine the life of human societies) but also of the highly complex regulatory affairs concerning human activities that significantly affect the state of the natural environment. In this volume, he explores four human-induced environmental problems – their historical antecedents and current situation – which have already become particularly critical on a global scale.

The most important of the heavy metals in terms of their environmental and health hazards, namely, lead, cadmium and mercury, are the subjects of his thorough review and assessment. The chapter devoted to these substances describes their applications, environmental releases, the most serious damages that have been observed so far, and the difficulties and results of international negotiations intended to reduce their use and environmental harm.

Solutions and practices for coping with the already globalized waste problem, including prevention, waste collection, recycling, and, in particular, hazardous waste disposal, vary from region to region and for different industrial sectors, being more or less effective. The same is valid for the goals, commitments, recommendations, and implementation to date of the waste-related international agreements and programs presented and evaluated by the author, which have been insufficient to fully and meaningfully mitigate the widespread adverse impacts.

The ozone layer plays an irreplaceable role in protecting the biosphere, absorbing a significant proportion of the UV radiation that can be lethal to living organisms. So, the consequences of this ozone shield being damaged or depleted would be catastrophic. However, the discovery of this threat was not easy either, as can be traced in this book. Perhaps it can be stated without exaggeration that the interventions that were made to phase out the emission of ozone-depleting substances – as detailed by the author – have been created within the framework of the most effective international environmental protection cooperation to date. Although the atmospheric residence time of these compounds is on the order of centuries, and the recovery of the 'ozone shield' is slow, there are clear signs of its healing.

The final chapter focuses on what is by far the most complex and challenging environmental problem of our time: the causes and consequences of climate change and the opportunities and difficulties associated with the international regulation of human activities that affect the climate system. In this case, too, prevention is essential, i.e., first and foremost, the reduction and, where possible, elimination of any human activities that are identified as having dangerous environmental impacts. In parallel, it is essential to prepare for or adapt to changes in environmental conditions that are already inevitable, especially those that are harmful or even destructive. The latter approach has its

limits since adaptation to accelerating and worsening environmental change is increasingly difficult and limited.

I can recommend this thought-provoking and readable book by Tibor Faragó to those who are interested in the most important environmental problems of our time and the process of their international management.

László Bozó, academician
Hungarian Academy of Sciences

INTRODUCTION

> "Our civilizations are at risk because we are misusing natural resources and disturbing natural systems. […] Atmospheric systems have been disturbed, threatening the climate regime to which we and other forms of life have long been adapted. [We have also] significantly damaged the stratospheric ozone layer. Pollution of air, soil, fresh waters and the oceans has become a serious and continuing threat to the health of humans and other species. Humanity is causing emissions of arsenic, mercury, nickel, and vanadium that are now double those from natural sources; zinc emissions are triple and those from cadmium and lead are respectively five and eighteen times higher than natural rates. […] Much of what needs to be done if we are properly to care for the Earth is of global significance and requires a global response."
>
> *IUCN-UNEP-WWF, 1991*[1]

INCREASING HUMAN INTERVENTION IN NATURE, INITIATIVES FOR A CLEAN ENVIRONMENT AND HEALTHY PLANET

The environmental impacts of human activities have become diverse and have increased over the past centuries, especially since the Industrial Revolution and the rise of globalization. The identification of these processes, their cause-and-effect relationships, and the assessment of the potential longer-term consequences have been made possible by the development of environmental monitoring systems, the systematic collection of data on socioeconomic changes, and thanks to the progress of scientific studies. The history and state of 'environmental globalization' and its international scientific and political dimensions have been comprehensively analyzed and evaluated in a previous book by the author.[2] In the present one, we explore in detail four specific cases of largely human-induced environmental hazards that have gradually become particularly and globally critical. We present the main stages of their recognition, the identification of their natural and anthropogenic drivers and the development of multidisciplinary scientific cooperation and international policy collaboration – including the key organizations, programs, and agreements – dedicated to resolving these problems, together with their critical assessment.[3]

International environment-related conflicts have accompanied societies throughout human history. For a long time, such clashes primarily arose due to – the direct or indirect – acquisition and

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[1] [IUCN-UNEP-WWF, 1991: pp. 4-5]

[2] "Our Common Environment and Globalization" [Faragó, 2024]

[3] The contents of this book also reflects the knowledge that the author has acquired not only from scholarly studies and literature but also from 'practice' when given the opportunity to participate in international forums on environmental issues from the 1980s onwards, followed by his involvement in the elaboration of multilateral programs and agreements. Among other processes, he was involved in (i) negotiations concerning reducing the utilization and harm of toxic heavy metals, and the preparation of the mercury convention (UNEP, 2003-2009), (ii) the finalization of the international strategy for the sustainable management of hazardous chemicals and wastes (SAICM, 2006), (iii) the elaboration of the global convention on climate change and subsequent tightening of its provisions (UNFCCC, 1991-2015), and (iv) resolving some of the controversies in international climate and ozonosphere protection legislations (1993-1997). He has published numerous articles and several books on these and some other environmental subjects since 1979, including the book published in Hungarian on the themes discussed extensively in the present book [Faragó, 2023].

exploitation of certain natural resources. Conflicts between nations stemming from transboundary environmental damage and/or pollution are mostly of a more recent origin.

- In addition to resource scarcity and/or surplus demand, other factors may have also played a role in some nations setting their sights on natural resources in areas under the jurisdiction of other nations or beyond national jurisdiction. The resulting conflicts of interest have a history stretching back thousands of years and have not often concluded peacefully. More recently, similar causes have underpinned many international confrontations [Westing, 1986[4]; Klare et al., 2011[5]]. The increasing demand for various natural assets (lands, freshwater, biological resources, minerals, etc.) and other factors (such as "unequal resource distribution") have contributed to the escalation of such bi- and multilateral tensions [Homer-Dixon, 1994[6]; UNEP, 2009; Faragó, 2018].
- Interstate disputes arising from transboundary pollution only began to proliferate from the beginning of the 20th century. An early conflict often cited in the scientific literature, arose because of the harm caused to nearby USA territory by air pollutants emitted from a smelter in the Canadian settlement of Trail in the 1920s [UN, 2006]. Prior to this, the 1909 treaty between the two countries already referred to transboundary water pollution problems and their prevention [Hall, 2007].[7] Other types of pollution have subsequently intensified, creating harmful effects of regional or even global importance (e.g., emissions causing 'acid rains' or ozone layer depletion).
- The multiplication of the hazardous environmental affairs and the conflicts they have induced have triggered the development of the international regulation of anthropogenic factors, the latter being their prime cause, especially since the 1970s. However, the regulation of the two more-or-less interlinked sets of such environmental problems – i.e., those associated with natural resources and harmful emissions – has evolved in dissimilar ways and at diverse paces, based on partly different principles. "Early international regulation of environmental activities dealt with conservation of common property resources subject to over-exploitation and customary international law first developed to restrain State actions causing transboundary harm, primarily economic harm, in the territory of another State. […] Given the wide range of environmental issues confronting humankind, many of which require a detailed, standard-setting regulatory response, it is not surprising that the vast bulk of international environmental law is found in tailor-made treaty arrangements. This is particularly so with respect to regulation of polluting activities likely to cause transboundary harm." [Redgwell, 2015: pp. 12-13]
- The thematic chapters of this book are devoted to describing the environmental releases of such substances derived from human activities that eventually had hazardous consequences of global significance and whose identification was followed by the elaboration of international policy programs and agreements, albeit with varying degrees of effectiveness.[8]

Pollution has rapidly increased in parallel with more extensive and intensive land use and the growing exploitation of natural resources.

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[4] "The nations of the world interact with each other in their pursuit of external natural resources […] in a bewildering variety of bilateral and multilateral ways. […] At the negative extreme of these spectra of international and domestic interaction are found overt threats of aggression and, of course, the actual pursuit of war." (p. 5)

[5] "Competition for control over vital, valuable raw materials has been a source of violent conflict since prehistoric times. Conflict over resources, such as gold, silver, spices, furs, timber, and slaves, was especially prominent and violent in the colonial wars and interimperial clashes that culminated in World War I. […] With the end of the Cold War, resource conflicts have again become prominent." (p. 1616)

[6] "Our research shows that environmental scarcity causes violent conflicts. […] The degradation and depletion of environmental resources is only one source of environmental scarcity; two other important sources are population growth and unequal resource distribution." (pp. 39-40)

[7] Boundary Waters Treaty (Article IV): "It is further agreed that the waters herein defined as boundary waters and waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other." (p. 695)

[8] Some publications by the author of this book have dealt with such topics (e.g., Faragó, 1981, 1993, 2007: greenhouse gas emissions; 2013: the global waste stream; 2015: toxic heavy metals; 2016, 2017: ozone layer depletion; 2016, 2018: international climate policies; 2018, 2022 /3.1.1./: transboundary environmental pollution).

- Increasing pressure on the environment has also involved the release of a wide range of pollutants that can travel long distances from their sources via the atmosphere and surface waters (seas and watercourses). This has been accompanied by a deterioration in the quality of the state of the environment worldwide. In addition to environmental transport processes, rapidly expanding international trade, goods, and passenger transport have inadvertently also contributed to the long-range propagation of harmful substances, including hazardous chemicals and wastes. The spread of unsustainable production and consumption patterns has also reinforced the globalization of these environmental problems.
- The socioeconomic development that has rapidly intensified since the middle of the last century has been referred to as the Great Acceleration. This has led to an increase in the exploitation (and degradation) of natural resources and the environmental releases of pollutants and hazardous substances [Steffen et al., 2004[9]; Steffen et al., 2007[10]]. That term is based on Karl Polanyi's concept of the 'Great Transformation', which led to the global market economy in the 20th century [Steffen et al., 2015: p. 2].[11] Even if not used in the current broad sense, Polanyi highlighted the dangerous social and environmental impacts (especially those related to land use) that occur under the conditions of an unregulated market economy [Polanyi, 1944].[12]
- It is only since the 1970s that growing environmental pollution and the problem of waste have received considerable international attention. This delay was largely due to the accumulation of pollutants and wastes (including hazardous substances) in the environment and their harmful effects, which took longer to reach critical and clearly identifiable levels. In addition to the assessment of the economic consequences of rapidly increasing resource use, the 1972 report of the Club of Rome made clear that the capacity of the natural system to absorb "the effluents of human activity" is not boundless. Therefore, the latter is one of the 'limits to growth' (in line with the report's title). Moreover, the authors of the report also provided the above-mentioned thought about why this dangerous limiting issue might not be detected in due time [Meadows et al., 1972].[13] A similar conclusion about the finite absorptive capacity of the environment was formulated in the *Stockholm Declaration* adopted at the 1972 UN Conference on Human Environment: "(3.) We see around us growing evidence of man-made harm in many regions of the earth: dangerous levels of pollution in water, air, earth and living beings […]. Principle 6. The discharge of toxic substances or of other substances and the release of heat, in such quantities or concentrations as to exceed the capacity of the environment to render them harmless, must be halted in order to ensure that serious or irreversible damage is not inflicted upon ecosystems". [UN, 1972] Prior to this, the need to model and estimate the 'undesirable by-products' of economic activities, namely, the pollutant emissions generated on the 'output' side, had already

[9] "With dramatically increasing consumption, opportunities for industry have grown and will continue to do so [… and] have also led to large environmental impacts, including the emissions of air and water pollutants and other wastes […], also toxic and hazardous substances." (p. 84)

[10] "Great Acceleration truly began only after 1945. […] The exponential character of the Great Acceleration is obvious from our quantification of the human imprint on the Earth system" (pp. 617-618)

[11] Karl Polanyi / Polányi Károly: graduated from Eötvös Loránd University (Budapest). From the 1940s on, he continued his scientific career as a professor at universities in the USA.

[12] "To allow the market mechanism to be sole director of the fate of human beings and their natural environment, indeed […], would result in the demolition of society." (p. 73); Ch. 15: "Market and Nature".

[13] "The natural ecological systems can absorb many of the effluents of human activity […]. When any effluent is released on a large enough scale, however, the natural absorptive mechanisms can become saturated." (p. 68) "The danger of reaching those limits is especially great because there is typically a long delay between the release of a pollutant into the environment and the appearance of its negative effect on the ecosystem." (p. 81)

been emphasized with a view to facilitating the application of the solutions to these 'undesirable' problems [Leontief, 1970].[14]

- Since the early decades of the last century, human activities have transformed the world in a way and to an extent that it can hardly be grasped. The growing human population's encroachment on 'the order of nature' has gone global. We have arrived at a new era that has been dubbed the Anthropocene by some researchers [Crutzen & Stoermer, 2000[15]; Rockström et al., 2009; Vida, 2012[16]; Desai, 2019]. Human activities have significantly interfered with some natural processes that are considered key to the stability (dynamic equilibrium) of the global environmental system. In terms of the concept of Planetary Boundaries, some of the critical processes have already left the safe zones, surpassing the respective boundaries; this is particularly the case with the substantial human interference with the natural carbon, nitrogen, and phosphorus cycles [Steffen et al., 2015]. According to this conceptual approach, the same appraisal holds for the state of Earth's environment as a whole: viz., humanity has gone beyond Earth's 'safe operating space'.
- Besides and beyond improving the identification of and efforts to manage (reduce) particular global environmental hazards, it should have been perceived long ago that the state of the planetary environment as a whole is rapidly changing and deteriorating in the absence of a comprehensive and effective systems approach in terms of (holistic) research activities and policy interventions. If these tendencies continue, environmental conditions around the world may lead to Earth becoming less 'livable', at least for the majority of present and future generations.

Initiatives intended to halt environmental degradation. The inadvertent, dangerous global-level pressures on the environmental system – brought about by accelerated socioeconomic processes – must sooner or later come to an end. At least, it is 'likely' that these dangers will be recognized in due time and their anthropogenic drivers will be mitigated [McNeill & Engelke, 2014].[17] This can happen in many ways, and it is associated with more or less advantageous or partly even disadvantageous outcomes. For this reason, scientific investigations are of key importance in understanding how these environmental pressures have strengthened, what has happened so far, and what ought to occur in the future to avert further negative consequences. The evolution of the recognition and understanding of these globalizing environmental affairs, the policy responses to them until now, and the latter's inadequacy (in most cases) can be properly demonstrated by recalling some of the findings of earlier and more recent international assessments.

- ***1968-1972***. The increasing impairment of the environment was highlighted by a 1968 UN resolution that, among other things, referred to the adverse impacts of air and water pollution, soil degradation, waste production, and 'side-effects' of pesticides [UN, 1968].[18] Following and based

[14] "Pollution is a by-product of regular economic activities […]. It is the purpose of this report first to explain how such externalities can be incorporated into the conventional input-output picture of a national economy and, second, to demonstrate that […] computations can yield concrete replies to some of the fundamental factual questions that should be asked and answered before a practical solution can be found to problems raised by the undesirable environmental effects of modern technology and uncontrolled economic growth". (p. 262)

[15] "[S]everal climatically important 'greenhouse' gases have substantially increased in the atmosphere […]. Furthermore, mankind releases many toxic substances in the environment and even some, the chlorofluorocarbon gases, which are not toxic at all, but which nevertheless have led to the Antarctic ozone hole". (p. 17)

[16] "Humans have brought about radical changes in the biosphere and its functioning over the last two to three centuries, creating a new era, the Anthropocene. […] Humanity, which has grown by orders of magnitude in both numbers and demands, is now facing the problem of the finiteness of natural resources and sinks." (p. 65)

[17] "But the Great Acceleration will not last long. […] Sometime soon people will likely moderate their impact on the Earth […]. No one can say when and how fast such shifts will take place. But when they do, the Anthropocene will have entered a new stage, perhaps a less worrisome one". (p. 209)

[18] The General Assembly "Noting, in particular, the continuing and accelerating impairment of the quality of the human environment caused by such factors as air and water pollution, erosion and other forms of soil deterioration, waste, noise and the secondary effects of biocides, which are accentuated by rapidly increasing population and accelerating urbanization".

on this resolution, preparations for the 1972 Stockholm environment conference began. At that UN conference, the participants adopted a declaration and an action plan in which they expressed their concern about the increasing levels of pollution and environmental degradation and reached a consensus on the need for coordinated international action, including global environmental monitoring and risk assessment, and a reduction in the environmental release of hazardous substances [UN, 1972].[19]

Logo of the 1972 UN conference

- ***1982-1987***. In the 1980s, many environmental problems were mentioned as increasingly harmful. Moreover, it was made clear that although international efforts to cope with them had begun in the 1970s, they had proved to be inefficient [UNEP, 1982].[20] Therefore, this environmental damage caused by people gradually worsened their own quality of life (i.e., had a negative repercussion on them). That UNEP report included the 'big question' that could not be handled at that time with sufficient certainty (ibid: p. 57): "At the end of the 1970s, therefore, despite very great increases in knowledge, it was possible to ask the same central question as at the beginning – 'is the world environment changing in ways that could be seriously detrimental in the long term to the well-being of humanity?' – and still not be sure of the answer." The report of the World Commission on Environment and Development reiterated the fact of growing human interference in the planetary environment and urged agreement on and the implementation of an adequate global program: "Over the course of this century, the relationship between the human world and the planet that sustains it has undergone a profound change. When the century began, neither human numbers nor technology had the power radically to alter planetary systems. As the century closes, not only do vastly increased human numbers and their activities have that power, but major, unintended changes are occurring in the atmosphere, in soils, in waters, among plants and animals, and in the relationships among all of these. […] The next few decades are crucial. The time has come to break out of past patterns." [WCED, 1987: extracts from pars. 101-104]
- ***2012-2015***. On the twentieth anniversary of the historical 'Earth Summit' (the UN Conference on Environment and Development), a high-level conference was convened with the objective of evaluating the implementation of *Agenda 21* (adopted in 1992), renewing the commitment to sustainable development, and agreeing on what more needs to be done, in particular in terms of addressing the unsustainable consumption and production patterns [UN, 2012; Faragó & Láng, 2012; Faragó, 2012]. In this regard, special attention was paid to the critical environmental factors, as the socioeconomic drivers of environmental pressures were continuing to intensify and were accompanied by "increased emissions of pollutants and wastes and destructive resource extraction" [UNEP/GEO, 2012].[21] In addition, one set of provisions of the outcome document of that conference[22] eventually led to the elaboration of a new comprehensive sustainable development agenda, finalized in 2015, with time-bound targets, inter alia, for the substantial

[19] *Action Plan*: (71.) "[M]inimize the release to the environment of toxic or dangerous substances, especially if they are persistent substances such as heavy metals and organic chlorine compounds"; (85.b) "Consideration of the appointment of appropriate intergovernmental, expert bodies to assess quantitatively the exposures, risks, pathways and sources of pollutants of international significance".

[20] "Carbon dioxide concentrations in the atmosphere continued to rise, concern about acid rains grew, and that about man's impact on stratospheric ozone remained. […] much concern was expressed over the enormous increase during the decade in the volume and number of man-made chemicals reaching the environment." (pp. 7-9) "The 1970s brought into focus the fact that international co-operation is essential to solve environmental problems, and several international and regional actions to protect and develop the environment were undertaken in the 1970s; it is difficult to contend, however, that the international system is yet as efficient as it should be." (p. 63)

[21] "Drivers such as population dynamics, economic demand and unsustainable consumption and production patterns are processes that lead to impacts on the environment. These drivers often directly or indirectly result in environmental pressures including increased emissions of pollutants and wastes and destructive resource extraction. Such pressures cause changes to the environment with concomitant impacts on both humans and ecosystems." (p. xix) "Drivers of environmental change are growing […] they are exerting unprecedented pressure on the environment. Most forms of consumption and production use the environment as a source of raw materials and as a sink for wastes." (p. 23)

[22] "Sustainable development goals". [UN, 2012: paras. 245-251]

reduction of air, water, and soil pollution, environmental releases of hazardous chemicals, and waste generation [UN, 2015[23]].[24]

- ***2019-2021***. Enormous progress has been made in international environmental science and policy collaboration since the 1970s, but this has not proved sufficient to solve most of the environmental problems that have gradually become of global significance. The UNEP's 2019 and 2021 reports analyzed this situation in detail, with a particular focus on the adverse impacts on human health. According to the former report, the unhealthy state of our planet's environment is caused among other factors, by high levels of pollution and waste streams [UNEP/GEO, 2019].[25] The other report also emphasized the problems of hazardous waste releases containing toxic heavy metals, persistent organic pollutants, and other chemicals, besides the rising greenhouse gas emissions and their atmospheric concentrations [UNEP, 2021].[26]

Healthy environment and human rights. While the impacts of increasing large-scale changes in the environmental conditions on societies vary in different regions, the *universal* right to a healthy environment has recently been acknowledged as one of the fundamental human rights. Its realization is essential not only in the present but also for future generations but will be difficult to achieve if the latter inherit a continuously deteriorating environment. The aforementioned 1972 declaration already interlinked care and responsibility for the planetary environment and the human right: "6. A point has been reached in history when we must shape our actions throughout the world with a more prudent care for their environmental consequences. Through ignorance or indifference we can do massive and irreversible harm to the earthly environment on which our life and wellbeing depend. Principle 1. Man has the fundamental right to freedom, equality and adequate conditions of life, in an environment of a quality that permits a life of dignity and well-being, and he bears a solemn responsibility to protect and improve the environment for present and future generations." [UNCHE, 1972] That human right was unambiguously formulated only half a century later, subsequently adopted by the UN Human Rights Council and the UN General Assembly. (Perhaps, the most expressive indication of this global level of interconnectedness is provided by the title of the recent UNEP environmental report, which reads 'Healthy Planet, Healthy People' [UNEP/GEO, 2019].)

- ***The environmental conditions for a human life*** of dignity and well-being have been described and interpreted diversely – for instance, as a clean, healthy, adequate, safe, or sustainable environment [e.g., Bándi, 2009].[27] More specifically, the satisfaction of basic human needs, the most essential preconditions for a decent human life, can be threatened by the lack of some resources of 'vital' importance (e.g., safe drinking water) and/or by poor environmental quality caused, for instance, by the release of different hazardous substances into the environment. These

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[23] Sustainable Development Goals and targets: 3.9, 6.3, 12.4, 14.1. In an earlier scientific paper, the author of this book provided a detailed overview of the historical background to this UN program and its specific sustainable development goals/targets [Faragó, 2016].

[24] An Open Working Group (OWG) was established for drafting the Sustainable Development Goals which became a core component of the '2030 Agenda'. The OWG was co-chaired by Csaba Kőrösi (Permanent Representative of Hungary to the UN), and Macharia Kamau (Permanent Representative of Kenya to the UN).

[25] "The planet is becoming increasingly unhealthy through the negative impacts of biodiversity loss (including pollinators, coral reefs and mangroves), climate change and other air pollution, water pollution, ocean pollution and depletion, and land use change. […] The pressures arise from massive use of chemicals (many with toxic health and environmental implications), huge waste streams (many largely unmanaged), committed and intensifying climate change impacts" (p. xxix); "Environmental pollution is still a major source of damage to the health of the planet". (p. 76)

[26] "The release of hazardous waste into the environment continues to have a significant role in its deterioration. […] hazardous waste and more specifically e-waste contain hazardous substances such as lead, cadmium, mercury, persistent organic pollutants (POPs), asbestos and chlorofluorocarbons […]. This highlights the need to improve the management of chemicals and waste to limit their interactions with nature". (pp. 76-77) "Despite the fall in emissions in 2020, it seems that atmospheric concentrations of greenhouse gases, which are what affects the climate, will continue to rise". (p. 121)

[27] "The subject matter of the right to the environment […] is understood in the literature [as]: a healthy environment (an environment that is adequate for human life and health, and free from harmful effects […], an environment that is safe, undisturbed, aesthetic, harmonious, beneficial for and worthy of human life." (p. 30)

issues are interrelated. However, we are primarily concerned here with the latter, i.e., environmental contamination in its broadest sense on a global scale. However, environmental quality criteria cannot be limited to a human-centered approach. The *Earth Charter*, initiated in 1992 and adopted in 2002, took a broader view of why and how it is necessary to preserve the healthy biosphere in its entirety and what human rights and obligations this entails [Earth Council, 2002[28]]. According to the Lancet Group, because of the serious adverse effects of pollutants on human health and the environment in general (viz., 'planetary health'), more effective pollution reduction (foremost, prevention) efforts are necessary worldwide [Landrigan et al., 2017; Landrigan & Fuller, 2018[29]]. To facilitate this, they proposed the establishment of a Global Pollution Observatory through the collaboration of the WHO and UNEP.

- ***The need to formulate and declare the universal human right to a healthy environment*** has been triggered by the intensification and recognition of environmental processes being directly or indirectly injurious to human health (including especially those discussed in the following chapters). Whilst this right appeared only tangentially in the 1972 *Stockholm Declaration* (as mentioned above), its concretization was already raised in the course of deliberations by the representatives of UNEP and the Council of Europe. The simplest solution would have been to supplement existing human rights documents with environment-related provisions [Kiss, 1976].[30] It also seemed reasonable to produce a separate international instrument (a declaration or charter) because of the multiplicity of relevant environmental and health aspects, but also with the clarification that the various human rights are intertwined [Untermaier, 1978; Kiss, 1989; Symonides, 1992; Cullet, 1995[31]; Fodor, 2015]. As mentioned above, all these concepts refer not only to environmental conditions being necessary for human health and well-being but also to the 'health of the environment' itself: "The impact of various forms of pollution on human health is well documented, and environmental quality standards for the protection of human health have been established for different pollutants and environmental media, based on scientific research to determine 'no adverse effect' concentration and exposure levels below which there is no significant health impact. […] Such impairments of the quality of life as a result of environmental conditions, though falling short of actually harming human health, should nevertheless be considered as infringements of the right to a healthy environment sensu lato. Indeed, a healthy environment is to be seen not merely as an environment that is healthful for human beings, but also as an environment that is itself 'healthy'." [Déjeant-Pons & Pallemaerts, 2002: p. 20] The same applies to intergenerational 'environmental justice'; that is, the ethical responsibility that no generation should leave the planet's environment to future generation(s) in a worse state than it inherited it from its predecessors, which includes obligations both in terms of the sustainable use

[28] "The resilience of the community of life and the well-being of humanity depend upon preserving a healthy biosphere with all its ecological systems". (II.2. a) "Accept that with the right to own, manage, and use natural resources comes the duty to prevent environmental harm and to protect the rights of people. […] Prevent pollution of any part of the environment and allow no build-up of radioactive, toxic, or other hazardous substances." (II.6. c, d)

[29] "Despite the great magnitude of its effects on human health and the environment, pollution from industrial, automotive and chemical sources has been gravely neglected in the international development and global health agendas […]. In many parts of the world, the burden of disease and death due to pollution is increasing." (pp. 2-3) "Sustainable long-term control of pollution and mitigation of climate change will require that societies […] move away from pollution control to prevention of pollution at source by fundamentally changing societal patterns of production, consumption and transportation." (p. 9)

[30] "Il y a été proposé de l'ajouter à la déclaration universelle des droits de l'homme, au pacte des Nations Unies sur les droits économiques, sociaux et cultures […]. Quant aux organes de recours, le droit à l'environnement pourrait être garanti par les instances existantes dans la cadre des instruments de protection des droits de l'homme." (p. 18)

[31] "The inclusion of an environmental dimension in the human rights debate has become necessary in view of the recognition of the pervasive influence of local and global environmental conditions upon the realization of human rights. In legal terms, the new linkages will come to enhance the protection in both fields". (p. 25)

of natural resources and the limitation of pollution [Weiss, 1992[32]; Norgaard, 1992[33]]. This does not entail the complete abandonment of the extraction of non-renewable resources and the total prevention of other burdens on the environment or of pollution [Nagy, 1994: p. 58]. These requirements have also been referred to in the context of national legislation and strategy-making in Hungary [Fülöp, 2012; Bartus, 2013; Bándi, 2013].

- ***International documents adopted under the auspices of the UN*** have included some notions and contexts associated with environmental rights and obligations since the 1960s. In most cases, they have mentioned only in general terms the requirement of the harmony of socioeconomic development and nature and the importance of environmental protection, but without any elucidation of what is meant by an environment of adequate quality for human life [UN, 1969: 13(c), 25(a); UN, 1972, 1990, 1995, 2000]. In other instances, in addition to the general criteria of environmental sustainability and the right to sovereignty of people and nations over their natural resources, more specific references have been made, at least to the requirements of avoiding environmental harm to human health. In this spirit, the *World Charter for Nature* addressed the discharge of pollutants and wastes that threaten natural systems (with only a single allusion to the negative feedback on human well-being): "11. Activities which might have an impact on nature shall be controlled, and the best available technologies that minimize significant risks to nature or other adverse effects shall be used, in particular: […] (e) Areas degraded by human activities shall be rehabilitated for purposes in accord with their natural potential and compatible with the well-being of affected populations. 12. Discharge of pollutants into natural systems shall be avoided and: (a) Where this is not feasible, such pollutants shall be treated at the source, using the best practicable means available; (b) Special precautions shall be taken to prevent discharge of radioactive or toxic wastes." [UN, 1982] The *European Charter on Environment and Health* included among the obligations of public authorities the prevention of the release of substances dangerous to human health and the environment, such as ozone-depleting substances, greenhouse gases, persistent chemical pollutants, and hazardous wastes [WHO, 1989].[34] The strategy *Caring for the Earth* was even more emphatic about human activities (such as pollution, emission of greenhouse gases and ozone-depleting substances, destruction of ecosystems, etc.) that are already at a global level dangerous to the life-support systems that are "the ecological processes that keep the planet fit for life" [IUCN-UNEP-WWF, 1991].[35]

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[32] "[E]ach generation should be required to maintain the quality of the planet so that it is passed on in a condition no worse than that in which it was received. Each generation should be entitled to quality comparable to that enjoyed by previous generations". (p. 22)

[33] "Sustainability reasoning […] weights current and future generations more or less equally. […] Legislative decisions to protect individual species, set aside land for national parks, establish soil conservation agencies, and limit pollution can be interpreted as efforts to protect the rights of future generations. […] International accords such as the Montreal Protocol to protect the ozone shield clearly limit the rights of current peoples in order to protect the assets of future peoples." (pp. 94, 112)

[34] *Principles* "9. Governments, public authorities and private bodies should aim at both preventing and reducing adverse effects caused by potentially hazardous agents and degraded urban and rural environments." *Priorities* "1. Governments and other public authorities should pay particular attention to the following urgent issues of the environment and health at local, regional, national and international levels and to take action on them: global disturbances to the environment such as the destruction of the ozone layer and climatic change; the environment and health impact of: […] persistent chemicals and those causing chronic effects; […] hazardous wastes including management, transport and disposal".

[35] "Life-support systems are the ecological processes that shape climate, cleanse air and water, regulate water flow, recycle essential elements, create and regenerate soil, and keep the planet for fit life. Human activities are radically altering these processes through global pollution and the destruction or modification of ecosystems. […] Climate change and ozone depletion are new global threats. At the same time, old pollution problems that once were local in scale now affect large regions. […] Many soils and groundwaters have been so contaminated by heavy metals and persistent organic compounds that they have become unusable. […] Pollution is the process overloading the Earth's ecosystems with damaging materials or waste energy. It has grown from a local nuisance to global menace." (pp. 27, 29)

- ***Cooperation regarding the environmental aspects of human rights has strengthened since the early 1990s***, largely catalyzed by the preparations for the 1992 'Earth Summit'. At a conference held in Bergen (Norway) in 1990, participants even drafted the text of an international charter of environmental rights and duties, but eventually, it was not submitted to the UN conference. Nevertheless, the concrete outcome of this 'Bergen process' was the 1988 *Aarhus Convention* which granted public rights to access to information and justice, and for participation in decision-making regarding environmental matters "in order to contribute to the protection of the right of every person of present and future generations to live in an environment adequate to his or her health and well-being" [UNECE, 1998]. With this, some basic environment-related rights were established, at least at the pan-European level.[36]

Logo of the 1992 UN Conference on Environment and Development

- ***The United Nations Commission on Human Rights*** (UNCHR) has become the primary forum for further in-depth discussion on environmental rights at the global level. This body compiled a report in 1994 on the relationship between human rights and the environment, in which the relevant passages of the declarations adopted at the 1992 UN conference (UNCED) and the 1993 Vienna Conference on Human Rights were taken into account [UN, 1992; UN, 1993[37]]. Among the most essential environmental factors, the report addressed the effects of pollution, toxic and hazardous substances, and waste on the upholding of human rights [UNCHR, 1994].[38] This report laid the foundation for the further work on this issue by the Commission and, from 2006 on, by its successor, the UN Human Rights Council (UNHRC). The need to recognize environmental rights was reinforced by the 2002 World Summit on Sustainable Development [WSSD, 2002[39]]. But even after that, it took a long time (until 2018) to finalize the text of the fundamental principles on environment-related human rights, followed by a resolution of the Council on 8 October 2021 on 'The human right to a clean, healthy and sustainable environment' [UNHRC, 2021]. The latter has finally and unambiguously clarified the link between the realization of human rights and protection of the environment, and vice versa – that is, the negative implications of environmental 'mismanagement' on the enjoyment of human rights.[40] Subsequently, the Council's resolution was endorsed by the UN General Assembly [UNGA, 2022]: "The General Assembly, […] 1. Recognizes the right to a clean, healthy and sustainable environment as a human right; 2. Notes that the right to a clean, healthy and sustainable environment is related to other rights and existing international law; 3. Affirms that the promotion of the human right to a clean, healthy and sustainable environment requires the full implementation of the multilateral environmental agreements under the principles of international environmental law".

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[36] The author of this book was a member of the official national delegation to that UNECE conference held in Aarhus (Denmark) in 1998 where, besides the 'Aarhus convention', two other legal instruments were adopted on controlling/reducing the emissions and transboundary movements of toxic heavy metals and persistent organic pollutants. These environmental matters and their scientific and policy dimensions are extensively described in the following two chapters.

[37] "11. The right to development should be fulfilled so as to meet equitably the developmental and environmental needs of present and future generations. The World Conference on Human Rights recognizes that illicit dumping of toxic and dangerous substances and waste potentially constitutes a serious threat to the human rights to life and health of everyone."

[38] (4.) Pollution, discharge of toxic and dangerous products (5.) Transboundary transfer of hazardous wastes.

[39] "169. Acknowledge the consideration being given to the possible relationship between environment and human rights, including the right to development, with full and transparent participation of Member States of the United Nations and observer States."

[40] "*The Human Rights Council* […] *Recognizing* that sustainable development, in its three dimensions (social, economic and environmental), and the protection of the environment, including ecosystems, contribute to and promote human well-being and the enjoyment of human rights, […] *Recognizing also* that, conversely, the impact of climate change, the unsustainable management and use of natural resources, the pollution of air, land and water, the unsound management of chemicals and waste, the resulting loss of biodiversity and the decline in services provided by ecosystems interfere with the enjoyment of a clean, healthy and sustainable environment, and that environmental damage has negative implications, both direct and indirect, for the effective enjoyment of all human rights".

INCREASING ENVIRONMENTAL PRESSURES AND THE RESPECTIVE ENVIRONMENTAL POLICY RESPONSES

The interdependence of societies has been reinforced by the growing demands on natural resources, the environmental release of harmful substances, and their transboundary impacts. It has become evident that international cooperation is essential for monitoring and assessing these processes, followed by the determination and implementation of appropriate measures to address them. The elaboration of such international programs and agreements has accelerated over the past few decades, and nowadays, there are hundreds of such multilateral policy and legal instruments. Their objectives and provisions cover all large-scale environmental problems (that have been recognized/identified by scientists and acknowledged by policymakers), their intertwined natural and anthropogenic drivers, and the adverse consequences at global, continental, and regional levels.

Such global affairs are discussed in the following thematic chapters of this book that have become particularly critical – namely, we overview their emergence and scientific exploration; moreover, the evolution of related international scientific and political collaboration, including the key outcomes, i.e., the institutional frameworks, policy, and legal instruments. We also appraise the effectiveness of these institutions and instruments and extract the main conclusions and lessons learned.

- The key stages of the scientific cognition of the causal links concerning each topic are revealed (preferably based on the primary scientific literature sources) because we believe it is instructive to see how the knowledge about these hazards has crystallized and how scientific certainty about them has strengthened.
- These are complex problems of global significance that concern all societies, albeit in different ways and to different degrees in terms of their socioeconomic drivers and effects. That is why it also seemed essential to recall how international cooperation began and progressed regarding these globalizing environmental subjects.
- Without these international efforts – environmental monitoring, research activities, the development and the (more or less effective) implementation of the agreed policies and measures – hazardous human interventions in the state of the environment and their impacts would have continued to intensify, making the world approach even faster some dangerous boundaries or ‘tipping points’. Such international policy-making is usually accomplished by formulating general objectives, more concrete goals and time-bound targets, recommendations, and/or (common and differentiated) commitments and incorporating them into the frameworks of the respective strategies, programs or agreements, which are also presented below.

Four human-induced global environmental hazards are the themes of the following chapters, for which solutions or at least mitigation, international policy, and/or legal instruments have been developed following the recognition of their causes and hazardous influences. Despite the substantial differences in how these problems arose and strengthened, how their causes were identified and justified, and what specific policies, measures, and techniques were deemed appropriate for their treatment, these scientific research and policymaking processes share a number of similarities. Among other things, they were all characterized (i) by fierce shorter or longer-term debates among researchers about the respective problem’s possible causes and impacts (or even about its existence, per se), and afterward also (ii) by serious conflicts of interests regarding the sharing of responsibilities related to these environmental threats and undertaking commitments to address them. No matter how old these environmental affairs are, they will be with us for a rather long time to come. Of course, this duration depends on the effectiveness of the relevant international programs and agreements.

This is not only why it is essential to get to know about these scientific investigations and decision-making developments but also because the experiences gained through studying them can improve the identification and solution of other or potential future large-scale, environment-related problems that could make it even more difficult to achieve and maintain a sustainable relationship ('harmony') between human societies and the natural environment.

- ***The first of the following chapters is about toxic heavy metals***, of which the various uses of lead and mercury date back thousands of years. These heavy metals and cadmium, as well as their compounds, have proven to be very useful for a multitude of purposes, but it is almost incomprehensible why their health and environmental harms remained undiscovered for so long. Current international programs and pan-European agreements cover all these three materials. However, a global, legally binding instrument has only been adopted on the gradual phase-out of mercury (and its compounds) concerning its still-existing applications.
- ***Increasing environmental pollution, waste production, and the harmful consequences thereof*** have also become global-level problems since the middle of the last century. This environmental pressure has been strengthened by the ever-increasing release of such harmful substances worldwide and their long-range transmission in the environment. The latter includes their long-distance 'travel' from their sources, not only in the natural environment (the atmosphere or water bodies) but also by human 'mediation', viz., the legal or illegal international 'waste trade' and transport. The second thematic chapter that follows is dedicated to describing the main components of these pollutant and waste flows and, furthermore, to the presentation and evaluation of the international organizations, programs, and agreements addressing these problematics.
- ***The production, use, and inadvertent emission of ozone-depleting substances*** (ODS) started and then rapidly accelerated from the first half of the twentieth century onward. The understanding of the threat they caused to the ozone layer came a few decades later (from the end of the 1970s), and international agreements were drawn up rather soon after this to avert this global hazard. This was possible due to the effective 'science-policy dialogue' on this issue (especially after the discovery of the 'ozone hole'). The very short time between the recognition of the causes of this process and the decisions on the relevant measures for phasing out the ODS and using alternative, 'ozone-friendly' chemicals is in no way comparable to the extremely long delay in policy responses following the exploration of other perilous phenomena which are also detailed in this book. Of course, in order to 'save' the ozone layer, the full implementation of all the commitments approved so far by the international community is essential. The third thematic chapter is about the history, current status, and prospects of ozone layer research and protection.
- ***Climate change*** is the subject of the final chapter – the global change that is rapidly unfolding. It has taken so many decades since hypotheses were created about the atmospheric greenhouse effect and the main factors influencing the state, and 'operation' of and changes in the Earth's climate system – i.e., the sources and sinks of greenhouse gases, the extraterrestrial and anthropogenic drivers ('forces') affecting this huge system, etc. – and the adoption of the global convention on combating this dangerous and escalating problem. In this case, we again review and assess the evolution of scientific and policy-related cooperation, with special emphasis on the relevant international programs and agreements.

RELATIONSHIPS OF HAZARDOUS ENVIRONMENTAL PROCESSES

Neither these global environmental issues nor the relevant response policies and measures adopted at the international level and their effects are completely independent. There are significant similarities and interconnections between them. This is why applying the 'systems approach' is absolutely necessary in the context of environmental research and for coherent policy-making, as mentioned before, in addition to analyzing and addressing the specific problems separately.

Similarities. In addition to the main driving forces behind global environmental challenges, namely, the world population growth and the widespread propagation of unsustainable production and consumption patterns, the hazardous issues discussed here have other similarities that make them especially difficult to overcome. To some extent, these apply alike to the release, transmission, and/or build-up in the environment of harmful substances – pollutants, hazardous chemicals, and wastes (in whatever state, that is, in solid, liquid, or gaseous forms) – and to some of the adverse influences caused by them. (In the following, we will sometimes refer to these substances together as 'pollutants' in the broadest sense and their environmental releases as 'pollution').

- ***A wide range of these substances and their sources*** must be considered in research studies and the development of policies. This statement is equally valid for those that affect the ozone layer (causing its 'thinning') or the planet's climate (via strengthening the greenhouse effect of the atmosphere), toxic heavy metals (including their various compounds), and for a multitude of chemicals and wastes released to the environment. Concerning the 'climate problem', the rising atmospheric levels of carbon dioxide from coal combustion were initially in the focus of the researchers, and only later were observations and analyses extended to other trace gases (and aerosols or particulate matters) and their anthropogenic sources. Given the diversity of these sources and the variety of economic activities behind these emissions, the most recent international climate change agreement referred to 'economy-wide' emission reduction targets [UNFCCC/PA, 2015: Art. 4.4]. A similarly broad approach has been required for ozone-depleting substances and likewise for hazardous chemicals and wastes, such as persistent organic pollutants, mercury and its numerous compounds [VCPO/MP, 1987: Annex A; SC, 2001: Annex A & B; Art. 6; MCM, 2013: Art. 3, Art. 4; Faragó, 2015].
- ***The long-range environmental transport of these pollutants and their long-term adverse influences*** are also common features of these environmental processes. Therefore, it is no longer just a question of transboundary environmental damage leading to bilateral or regional international conflicts but of increasing worldwide concern because of the global-scale deleterious consequences. In addition, with each of the affairs examined here, there is a lengthy recovery or stabilization ('adjustment') period of the damaged environmental component even after the complete cessation of the causes of the hazardous changes (e.g., eliminating the environmental release of the pollutants in question). These aspects of such globalizing environmental affairs were already raised many decades ago [Meadows et al., 1972].[41]
- ***The harms stemming from these environmental pressures***, i.e., their negative socioeconomic and ecological effects, are also manifold. This is particularly valid for all the cases considered in the subsequent chapters. For instance, the environmental releases of toxic heavy metals and the substances depleting ozone layer can lead to various negative influences on human health and ecosystems [WHO, 1995; UNEP, 1992, 1998]. The implications of ongoing climate change have also been addressed for a long time; in addition to threats to the natural environment and human

[41] "Many pollutants are globally distributed; their harmful effects appear long distances from their points of generation." (p. 69) "Whenever there is a long delay from the time of release of a pollutant to the time of its appearance in a harmful form, we know there will be an equally long delay from the time of control of that pollutant to the time when its harmful effect finally decreases." (p. 82)

health, particular attention has been paid to the substantial impacts on water management, agriculture, and the energy sector [IPCC/WG-II, 2014].

These environmental problems are interrelated and these relationships should be considered when determining and implementing policies and measures to address them.

- ***The greenhouse effect and ozone-depleting substances*** (ODS). Ozone itself is a greenhouse gas, as is the large variety of ODS emitted unintentionally into the atmosphere. The assessment of the aggregate atmospheric greenhouse forcing effect of freons, halons, and other ODS emissions was particularly important before the approval and implementation of the international agreements on phasing out these substances [IPCC & TEAP, 2005].[42] At the same time, climate change also affects the state of the Earth's ozone layer.
- ***Heavy metals in waste***. There is a substantial degree of toxic heavy metal pollution in the natural environment, one of the sources of which is the production and disposal of waste containing lead, cadmium, or mercury. In the case of mercury, this also includes its atmospheric emissions from waste incineration [UNEP/GMA, 2019].[43]
- ***Microplastics and the ozone layer***. The increasing release of plastic waste into the environment has a particularly perilous impact on water ecosystems (marine and freshwater biomes), especially when plastic debris is broken down into microscopic fragments, in which process, the ultraviolet solar radiation plays a substantial role [UNEP/EEAP, 2020].[44] Therefore, the measures adopted and effectively implemented so far to 'save' the ozone layer indirectly mitigate the generation of microplastics.
- ***Hazardous chemicals and fossil fuels***. In addition to carbon dioxide, fossil fuel combustion is the key source of atmospheric mercury emissions. Mercury pollutants can spread over long distances and cause harms to human health and the environment far from their emission sources. This environmental burden is incorporated as one element in the theory of 'planetary boundaries' [Rockström et al., 2009].[45] Greenhouse gas emissions, climate change, and environmental hazards induced by hazardous chemicals also interact in several other ways [BRS-MCM, 2021].

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Consequently, the above-mentioned environmental issues, especially some of their socioeconomic drivers and interactions, must also be considered in their complexity to avoid either the cause-effect relationships being misinterpreted[46] or efforts at solving one of these hazards inadvertently causing the worsening of another one.

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[42] "Halocarbons are particularly effective greenhouse gases […]. Since 1970 the growth in halocarbon concentrations and the changes in ozone concentrations (depletion in the stratosphere and increases in the troposphere) have been very significant contributors to the total radiative forcing of the Earth's atmosphere. Because halocarbons have likely caused most of the stratospheric ozone loss […], there is the possibility of a partial offset between the positive forcing of halocarbon that are ODSs and the negative forcing from stratospheric ozone loss." (p. 91)

[43] "Emissions from waste that includes mercury-added products comprise about 7% of the 2015 global inventory". (p. 4)

[44] "When plastics are exposed to solar UV radiation they break down into potentially toxic microplastics […]. Microplastics are ubiquitous in the environment and are of growing concern, especially in aquatic ecosystems".

[45] "Chemical pollution also interacts with the climate-change boundary through the release and global spread of mercury from coal burning and from the fact that most industrial chemicals are currently produced from petroleum, releasing CO_2 when they are degraded or incinerated as waste." (p. 18)

[46] For example, there are often 'unfounded' (not properly justified) claims that the anthropogenic climate change is primarily 'to blame' for quite differing adverse phenomena. Imre Jánosi has referred to this in a recent paper: "climate change is all too often mentioned in the context of adverse environmental processes, even when the underlying causes are more likely to be the consequences of global overpopulation and pollution." [Jánosi, 2020: p. 4]

ENVIRONMENTAL POLICY COOPERATION AS A 'LEARNING PROCESS': THE ADOPTION OR REJECTION OF PREVIOUS SOLUTIONS AND THE IMPORTANCE OF SYNERGIES

> In the course of the evolution of international environmental policy cooperation, various principles, goals, procedures, and means of implementation have been incorporated into programs and agreements aimed at addressing specific environmental problems. If consensus was reached on one of these components of a policy or legal instrument, and it seemed to be applicable to another environmental issue, then it may again have been promisingly proposed for adoption, and in many cases indeed, passed (perhaps with some reasonable amendments). In this sense, policymaking is a 'learning process' – that is, it involves recalling and taking into account previous experiences and compromise settings during new rounds of multilateral deliberations. However, relying on and repeatedly accepting a "precedent should not be taken for granted, and consideration should be given to relevant special or emerging circumstances and demands" [UNEP, 2007, p. 2/17]. Despite the clear evidence of the usefulness of such learning from earlier instances, including the choice of potentially appropriate policy approaches, this solution has not been applied with consistency [SLG, 2001].[47] This may have been due to the fact that the multilateral cooperation process grew out of the resolution of bilateral environmental conflicts, but the respective experience in the formulation and implementation of policy and legal instruments could not provide sufficient support for solving large-scale or global affairs [Bándi, 1993].[48]

Where and how to intervene? One of the fundamental questions regarding environmentally damaging human activities was and remains whether to limit/modify/quit them or instead to moderate or tolerate their immediate harmful consequences. (For example, the latter would mean somehow enduring the worsening air quality caused by increasing pollution or coping with water scarcity due to a depleting aquifer in an area as a consequence of its overuse.) The preparation for such adverse changes may mean an increase in adaptive capacities (adaptability) and resilience – in light of the former's further strengthening or potential future unfavorable environmental conditions – and/or actual adaptation to changes that are already unavoidable or underway. In addition, attention should be paid to the nexus between various agreements (as well as the relationships between different policy programs) because measures taken in relation to one environmental matter may assist in or hinder the resolution of another. For this reason, it is essential to ensure the coherence of interventions aimed at different but interlinked problems [UNU, 1999].[49]

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[47] "[A]lthough society's response to global environmental change was clearly a long-term process unfolding over decades, most of our understanding focused on key discoveries and decisions and paid little attention to the historical connections among them. […] although most debates on how to improve social response were replete with analogies and lesson drawing, there was little critical discussion of what might be appropriately learned from the experiences of other problems and places". (p. xxi)

[48] Introduction: "International environmental law is based on a number of traditional international legal principles. […]. However, the scope of these principles is limited, as they were developed in bilateral relations. It has become increasingly clear that, in addition to these principles, more general rules are needed to protect the biosphere, the oceans, the ozone layer, migratory species, the world's genetic heritage or climatic conditions. Globalization of international environmental law can be understood especially in this sense. […] International regulation and cooperation can be the most important guarantee of environmental protection."

[49] "Co-ordination has the potential to improve each of these aspects of MEA effectiveness by promoting the coherence of rules and norms, […] and ensuring that the desired impacts on the environment of one regime do not undermine the desired impacts of another." (p. 10) "Overall, the concept of issue management may serve as a useful tool for enhancing and developing synergies between the MEAs and should be developed further. This might include consideration of the timing of work (agendas and work programmes) of various MEAs, with a view to avoiding the development of conflicting measures". (p. 23)

- ***Mitigation and/or adaptation***. A classic example of transboundary pollution is the release of sulfur dioxide into the atmosphere from coal-fired power plants. Contrary to the findings of Scandinavian professionals, the possibility of the long-range transmission of these pollutants was long doubted, primarily by some British government representatives, who deemed it unjustified to reduce this pollution and instead proposed to use liming to offset the acidification of lakes in Scandinavian countries [Hajer, 1993].[50] A much longer-lasting debate has emerged on whether preparing for the already inevitable changes in environmental conditions due to climate change (that is, adapting to them) should be considered of greater or at least equal importance to reducing the anthropogenic emissions of greenhouse gases (GHGs) or taking other actions to mitigate their rising atmospheric concentrations. The significance of both types of response policies was emphasized in the 1992 climate change convention. This 'mitigation-adaptation dilemma' was further addressed later, but placing unequal weights on these responses: (i) either by putting a stronger accent on limiting/reducing such emissions or (ii) just mentioning that setting stronger emission mitigation targets could facilitate adaptation efforts [UNFCCC/PA, 2015].[51]
- ***Prevention at the source of the contamination or end-of-pipe interventions***. It is best to prevent human-induced environmental problems ab ovo, i.e., to avoid them before they arise by means of deploying adequate control measures at their potential source(s). For industrial activities, such prevention can be achieved with 'clean production' [Zilahy, 2004].[52] This applies to all the issues we examine in detail in the forthcoming chapters. On many occasions, however, 'end-of-pipe' procedures have been preferred for a long time to moderate dangerous environmental influences. The latter focus on somehow treating (lessening/avoiding) the release of hazardous substances/pollutants to the environment instead of dealing with their generation due to human activities (viz., preferably by completely eliminating the formation of such pollution). A well-known and widespread example of this involves the desulphurization of flue gas from coal-fired power plants. Technological options for 'carbon capture' (for instance, the CO_2 removal from flue gas, i.e., its 'decarbonization') are also being explored, followed by the permanent storage or utilization of the separated carbon dioxide [Herzog & Drake, 1996[53]; IPCC, 2005; Faragó, 2013]. Even before this, and analogously, it was recommended at least to prevent the atmospheric emissions of ozone-depleting substances (for example, by recovering halogenated refrigerants from decommissioned refrigerators and the disposal/destruction of these chemicals), besides urging the phase-out of the production and consumption of these substances and substituting them with 'ozone-friendly' ones [VCPO/MP, 1989].[54] Instead of the 'end-of-pipe' solutions, the significance (nay, primacy) of addressing adverse environmental processes at their sources was recognized well before the conclusion of the respective international agreements, e.g., in raising

[50] "The British government emphasized that there was no firm evidence that its SO_2 emissions were responsible for fish deaths and acidification in the Swedish lakes […], it argued that tall stacks (to dilute and disperse pollution) and the liming of lakes (to counterbalance the acidification) were much cheaper and more effective means." (p. 52)

[51] (7.4.) "Parties recognize that the current need for adaptation is significant and that greater levels of mitigation can reduce the need for additional adaptation efforts".

[52] "Preventive environmental protection, narrowly defined, aims to reduce or eliminate harmful emissions and other environmental impacts at source. Reducing emissions in this way also reduces the amount of natural resources used. […] This preventive approach is reflected in the concept of cleaner production".

[53] "CO_2 capture and sequestration should be viewed as an insurance policy. This mitigation strategy is an end-of-pipe option, although, in general, a pollution prevention strategy is preferred." (p. 163)

[54] Decision I/12F: "[A] destruction process is one which, when applied to controlled substances, results in the permanent transformation, or decomposition of all or a significant portion of such substances". Helsinki Declaration: The Governments agree "to phase out the production and the consumption of CFC's […] as soon as possible […], phase out halons and control and reduce other ozone-depleting substances […], to accelerate the development of environmentally acceptable substituting chemicals".

the need to reduce the use of fossil fuels in energy systems [Glaser, 1982][55], or to get rid of mercury in all its applications [UNEP/GMA, 2002].[56] Similarly, recommendations and provisions for the safe disposal of hazardous waste have been included in international guidelines, programs, and agreements since the 1980s, besides placing increasing emphasis on preventing (or at least significantly reducing) its generation [UNEP, 1987].[57]

- ***Environmental burden-shifting***. When it turned out that some synthetic compounds (e.g., the above-mentioned refrigerants) were dangerous to the ozone layer, they were replaced first by alternatives that, although less or not at all harmful in that regard, had very high global warming potential. Therefore, these measures to save the ozone shield contributed to the enhancement of another global environmental threat. This contradiction could only be overcome by the production and application of ozone- *and* climate-friendly chemicals [VCPO/KA, 2016; Faragó, 2017]. Another example of 'burden-shifting' was when the waste problem thought to have been solved by waste incineration or landfilling led to substantial emissions of carbon dioxide and methane, which in turn strengthened the atmospheric greenhouse effect [IPCC/WG-I, 2013].

Precedents. When the intention has been to deal with newly discovered environmental challenges by developing policy or legal instruments, the possible relevance and application/repetition of some previously agreed general principles, solutions, or compromises also arose. The latter include precedents that have proven to be effective or at least acceptable by consensus for handling other environment-related affairs in the past.[58] In addition to the following examples, newer environmental agreements have made use of previous procedural provisions, inter alia, in connection with the conditions for entry into force, facilitation/enforcement of the fulfillment of commitments, or the rules of dispute settlement.[59]

- ***The precautionary approach***, although not yet specified using this term (but still meaning the avoidance of potential environmental harm in the broadest sense), appeared in the declaration on the exploration and use of outer space and also in the *Outer Space Treaty* [UN, 1962; OST, 1967[60]]. *The Convention on the Law of the Sea* referred to activities that are (only) likely to cause pollution and the latter's deleterious effects on the marine environment; moreover, it listed some countermeasures [UNCLOS, 1982[61]: Art. 1(4.), Articles 219, 221, 150(b)]. The *Vienna Convention for the Protection of the Ozone Layer* already explicitly referred to "precautionary

[55] Summary: "The greenhouse effect is not likely to cause substantial climatic changes until the average global temperature rises at least 1°C above today's levels. This could occur in the second to third quarter of the next century. However, there is concern among some scientific groups that once the effects are measurable, they might not be reversible and little could be done to correct the situation in the short term. […] Mitigation of the 'greenhouse effect' would require major reductions in fossil fuel combustion."

[56] (28.) "Reducing or eliminating anthropogenic mercury releases will require controlling releases from mercury-contaminated raw materials and feedstocks as well as reducing or eliminating the use of mercury in products and processes."

[57] Part I. General provisions (4): "States should initiate and co-operate in (a) The achievement and improvement of the environmentally sound management of hazardous wastes; (b) The development and implementation of new environmentally sound low-waste technologies and the improvement of existing technologies with a view to reducing the generation of hazardous wastes …". Part III. Control over disposal of hazardous wastes: (12) Duty to ensure safe disposal.

[58] We refer to such precedents in more details in Chapters 3 and 4.

[59] Zsuzsanna Kocsis-Kupper summarized the essence of international enforcement and dispute settlement mechanisms in one of her studies [Kocsis-Kupper, 2003: VII. pp. 65–69].

[60] Art. IX "States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose."

[61] Art. 1 "(4.) 'pollution of the marine environment' means, the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health …". Art. 204 "(1.) States shall, consistent with the rights of other States, endeavor […] to observe, measure, evaluate and analyse, by recognized scientific methods, the risks or effects of pollution of the marine environment."

measures" in an environmental context [VCPO, 1985]. Likewise, this notion was included in a working document on proposed legal principles compiled by an expert group assisting the work of the World Commission on Environment and Development in 1987, and then this principle was eventually included in the declaration adopted by the 1992 World Conference [WCED, 1987[62]; UN, 1992[63]]. That outstandingly significant declaration came up with the most frequently cited interpretation of precaution, viz., when and why it is reasonable to take certain measures against potentially emerging or strengthening environmental threats despite the "lack of full scientific certainty." The approval of the above documents can be seen as a turning point in the recognition of the importance of this approach. Recurrent references were made to the need for precaution in international environmental instruments from the mid-1980s onwards, including the protocol on ozone layer protection (1987), the convention on climate change (1992), the protocol to the convention on long-range transboundary air pollution on heavy metals (1998),[64] the convention dedicated to persistent organic pollutants (2001), and the strategy on sound/sustainable chemicals management (2006). In each of these cases, the gradual reduction of the scientific uncertainty about the injurious influences of some human activities (and the increasing evidence of such effects) led to the approval of much more concrete and definitive preventive measures that followed the initial and rather careful precautionary interventions. The most recent 'reminder' of the need for a precautionary approach is contained in the *Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction* (2023).[65]

- ***Common but differentiated responsibilities***. This principle has also become crucial in international negotiations on global environmental problems aimed at achieving a consensus about appropriate response policies. In general, different obligations have been defined for the developed and developing countries in light of their different historical responsibilities for the emergence of such global hazards. These differences were admitted not only in relation to the emissions of certain airborne pollutants and releases of other contaminants to the environment but also to the longstanding overuse and degradation of a multitude of natural resources: "The development of the presently industrialized countries took place in a setting which emphasized needs and de-emphasized limitations. The development of these societies have effectively exhausted a disproportionately large share of global resources - broadly defined to include both the resources that are consumed in productive activity (such as oil, gas and minerals), as well as environmental assets that absorb the waste products of economic activity and those that provide irreplaceable life support functions (like the ozone layer). […] The division of responsibility in this global effort emerges from the above arguments." [Munasinghe & King, 1991: pp. 2-3] In addition, when determining their obligations, the capacity of individual groups of countries to meet them was also taken into account. These two fundamental aspects were usually expressed together as the principle of the Common but Differentiated Responsibilities and Respective Capabilities (CBDRRC, or just abbreviated to CBDR): "When the CBDR principle is applied to the environmental context and environmental-related global goals (such as climate change

[62] Annex I. Summary of Proposed Legal Principles (1986): "11. States shall take all reasonable precautionary measures to limit the risk when carrying out or permitting certain dangerous but beneficial activities and shall ensure that compensation is provided should substantial transboundary harm occur even when the activities were not known to be harmful at the time they were undertaken."

[63] Rio Declaration on Environment and Development: "Principle 15. In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

[64] "[T]ake measures to anticipate, prevent or minimize emissions of certain heavy metals and their related compounds, taking into account the application of the precautionary approach, as set forth in principle 15 of the Rio Declaration on Environment and Development" [CLRTAP/HM, 1998].

[65] Art. 2 "The objective of this Agreement is to ensure the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. …" Art. 7: "In order to achieve the objectives of this Agreement, Parties shall be guided by the following principles and approaches: […] (e) The precautionary principle or precautionary approach, as appropriate" [UNCLOS/BBNJ, 2023].

mitigation), the underlying idea for differentiation lies in the heart of historic responsibility; in case of non-environmental related global goals (such as social and economic development), the core idea for differentiation thrives at the center of different national 'capacities and priorities' which each State carries." [Jolly & Trivedi, 2021: p. 38] In this environmental context, the greater responsibility of the developed (or industrialized) countries was expressed as early as during the preparations for the 1972 UN Conference (UNCHE) and much more concretely in the two reports approved by the UN General Assembly in 1987 [Sohn, 1973[66]; UN, 1987[67]; WCED, 1987[68]]. Eventually, this distinction (differentiation) approach was generally formulated and endorsed also as part of the *Rio Declaration,* and since then, it has been the most frequently quoted formulation of this principle in newer global environmental agreements [UN, 1992: Principle 7].

- ***Specific instances of and reasons for differentiation***. The widely dissimilar production and utilization volumes of chlorofluorocarbons (CFCs) in developed and developing countries were more than evident from the mid-20th century onward, but only when the ozone-depleting effect of these substances was discovered did it became important to reflect these differences in the obligations of these two country groups in international agreements on ozone layer protection [GORMP, 1986[69]; VCPO/MP, 1987]. Another particular facet of 'differentiated responsibility' was indicated in the above-cited 1987 UN report – namely, that a large proportion of hazardous waste was being produced in developed countries (moreover, they partly got rid of this waste by dumping it somewhere at sea) [WCED, 1987].[70] Acknowledging and dealing with the serious imbalance in responsibilities represented a major breakthrough in debates on controlling anthropogenic greenhouse gas emissions and other measures for coping with global climate change. In view of all this, it is understandable that consensus could only be reached regarding the coordinated management of these global hazards if these two groups of countries (the 'Global North' and 'Global South') assumed significantly distinct commitments along the lines of the CBDR principle [Getu, 2012[71]; UNFCCC, 1992; UNFCCC/KP, 1997]. More recently, this principle was reiterated and embedded in the environmental agreement on persistent organic pollutants [SC, 2001], the convention on mercury [MCM, 2013], and the latest legal instrument on climate change [UNFCCC/PA, 2015]. All these defined important obligations for developing countries that, however, still differed considerably from those imposed on the developed countries and whose fulfillment was conditional in many cases. In accordance with the CBDR principle (and as one of the preconditions mentioned above), the developed countries have also committed to supporting developing countries in implementing their commitments under these global

[66] Chinese proposal for Principle 4 of the Stockholm Declaration: "At the present stage, the world environmental issue falls into two categories. In the developing countries, most of their environmental problems are caused by under-development which prevented them from taking energetic measures to improve the environment. […] As to the few highly industrialized countries, where pollutions are most serious and even endanger the environment of neighbouring countries and that of the world, the speedy solution of this problem has become the strong desire of the people of the countries concerned and the world as a whole."

[67] Recommended action (68.): "(c) Development co-operation institutions should increase significantly their assistance to the developing countries for environmental restoration, protection and improvement".

[68] "103. The onus lies with no one group of nations. Developing countries face the obvious life-threatening challenges of desertification, deforestation, and pollution, and endure most of the poverty associated with environmental degradation. […] Industrial nations face the life-threatening challenges of toxic chemicals, toxic wastes, and acidification. All nations may suffer from the releases by industrialized countries of carbon dioxide and of gases that react with the ozone layer, and from any future war fought with the nuclear arsenals controlled by those nations."

[69] "High growth rates for CFCs 11 and 12 seen in OECD countries in the 1960's and 70's are not expected to return, even in developing countries where current demand is small." (p. 77)

[70] "75. Industrialized countries generate about 90 per cent of the world's hazardous wastes."

[71] "For instance, developed countries with less than 25% of the world's population were consuming 88% of the CFCs, which is over 20 times the per capita consumption of the developing countries. Similarly, developed countries are responsible for two-thirds of global carbon emissions from fossil fuel use in 1993. […] Hence, developing nations claim that developed countries are disproportionately responsible for creating ozone depletion and climate change problems, and they should take the lead in devising the solutions as well." (pp. 13–14) "The ozone layer regime has, however, successfully resolved the North-South dichotomy by allocating a fair share of responsibility to both groups and implementing the same, which can also be adopted in the climate change regime." (p. 43)

agreements by providing financial means. For such purposes, for instance, the Multilateral Fund was created in 1990 under the *Montreal Protocol* on the protection of the ozone layer. This 'model' was then followed by the establishment of the Global Environment Facility (GEF) in 1991 – a financial mechanism for supporting implementation of numerous environmental agreements, primarily assisting developing countries.[72]

- ***Outsourcing ('exporting') the implementation of commitments***. In some environmental treaties, the fulfillment of the environmental resource use or pollution limitation obligations of States Parties was made possible through some special forms of collaboration between two or more of them. Early examples included fishing restrictions on the high seas or the convention on whaling,[73] followed by negotiations from the 1960s onwards on catch quantities (quotas) to be allocated to each party and the terms of their transfer/sale to another party [Holt, 2001]. The international 'waste trade' has often meant the shipment of hazardous wastes from a developed country to a developing country that did not have the appropriate waste management regulations or technology and thus accepted the waste for disposal or recycling in return for compensation. (Evidently, this was a much cheaper solution than, for example, the cost of waste incineration or its other treatment in the exporting country). The adverse consequences of such transactions were highlighted in a 1987 UN report, and in the same year, a detailed guideline on the international conditions for the export of hazardous chemicals and wastes was adopted [UN, 1987[74]; UNEP, 1987[75]]. These antecedents played a major role in the elaboration and approval of the convention on transboundary movements of hazardous wastes [BC, 1989]. Although the protocol on ozone-depleting substances allowed for the international transfer of some production quotas from one Party to another, only a few Parties took advantage of this opportunity [VCPO/MP, 1987]. In comparison to the latter, a decade later, the greenhouse gas 'emissions trading' – together with two other cooperative mechanisms – introduced by the *Kyoto Protocol* on climate change was not only more practical and usable for many Parties, but such mechanisms also became part of the newest instrument, the *Paris Agreement* on this matter (UNFCCC/KP, 1997; UNFCCC/PA, 2015).[76]

* * *

Overall, the environmental pressures caused by societies have become global in scope and planetary in scale. This applies in particular to the deleterious effects of the "unsound management of chemicals" (including toxic heavy metals), the hazardous wastes (due to their "increased generation and complexity, and transboundary movement"), the imperilment of the ozone layer (due to the "world-wide emissions of certain substances [which] can significantly deplete and otherwise modify" that layer) and the growing anthropogenic emissions of greenhouse gases (catalyzing

[72] Several Central and Eastern European countries with an 'economy in transition', including Hungary, have also benefited from support provided by the Global Environment Facility to help them meet their obligations, inter alia under the international agreements on the ozone layer and climate protection [Pató & Faragó, 2004].

[73] International Convention for the Regulation of Whaling, 1946.

[74] (64.): "There is a growing awareness of the hazards associated with trade in chemicals, pesticides and some other products" (68.j): "Trade in hazardous industrial products, such as toxic chemicals and pesticides, and in some other products, such as pharmaceuticals, should be subjected to regulations to ensure sharing by the contracting parties, Governments and consumers of information on their environmental and health implications and on methods for their safe use and disposal."

[75] Cairo Guidelines: "At the present time, waste management differs substantially in different regions of the world, particularly according to their state of economic development. […] Although the guidelines have not been prepared specifically to address the situation of the developing countries, they nevertheless provide a framework for effective and environmentally sound hazardous waste management policies in those countries." (p. 3)

[76] The 1994 protocol to the pan-European convention on transboundary air pollution also allowed for 'joint implementation', but the rules of that cooperative mechanism were not subsequently defined. The 'quota trading' arrangements provided by some international agreements and also the EU's greenhouse gas emissions trading scheme are described in more detail in one of the author's previous studies [Faragó, 2011].

"dangerous anthropogenic interference with the climate system").[77] These processes are especially harmful and partly interrelated components of 'environmental globalization', which are also closely linked to the accelerating use and depletion of many natural resources. The UN Human Rights Council resolution on the human right to a clean, healthy, and sustainable environment endorsed by a UN General Assembly resolution obviously applies to all environmental factors that threaten the enjoyment of that right, including the global environmental issues mentioned above and discussed in detail in the following chapters [UNHRC, 2021; UN, 2022[78]]. For each of these problems, we traverse and evaluate the history of its emergence and reaching global significance, the scientific investigation of its causal links, the development and (more or less) effective implementation of the relevant response policies and measures proposed and introduced within the framework of widening international cooperation.

[77] The quoted passages are taken from the relevant international documents [SAICM, 2006; BC, 1989; VCPO/MP, 1987; UNFCCC, 1992].

[78] The General Assembly "1. Recognizes the right to a clean, healthy and sustainable environment as a human right; 2. Notes that the right to a clean, healthy and sustainable environment is related to other rights and existing international law; 3. Affirms that the promotion of the human right to a clean, healthy and sustainable environment requires the full implementation of the multilateral environmental agreements under the principles of international environmental law".

1. THE LEGACY OF TOXIC HEAVY METALS

THE LONG HISTORY OF USE AND UNREVEALED HARMS
OF QUICKSILVER, SILVERY LEAD, AND SILVERY-WHITE CADMIUM

Mercury barometer from the 19th century made in Hungary (photo taken by the author)

"The jars [of wine] must never be filled quite full […] and moreover leaden and not bronze vessels should be used."

Plinius Secundus, A.D. 75[79]

"In that direction […] lives a Hatter: and in that direction […] lives a March Hare. Visit either you like: they're both mad."

Lewis Carroll, 1865[80]

"The itai-itai disease was chronic cadmium poisoning caused by heavy metals such as zinc and lead contained in the water of the Jinzu River."

Noboru Hagino, 1956[81]

Lead, mercury, cadmium and their manifold compounds were long used in many products and industrial processes without awareness of their toxicity. Moreover, these toxic substances were released into the environment from some of these applications and other human activities. Once released, these pollutants can travel considerable distances in the environment (i.e., in the atmosphere and water bodies), causing health and environmental damage far from their source. It took a long time to identify these cause-and-effect links and then gradually limit the use of these heavy metals. The evolution of this environmental problematic, its globalization, and the development of the related international cooperation are presented and assessed in this chapter.

[79] The quote is translated from Latin and is part of an ancient recipe for preserving and sweetening wine for which lead pots were used. The harmful 'side effects' of lead in wine were only later identified. (Naturalis historia, Lib. XIV)

[80] In the novel by Oxford mathematics professor Lewis Carroll, the Mad Hatter is a fictional personification of the London hatters who did not realize that they were becoming ill due to the mercury vapor from the mercury nitrate used in hat making. (Alice in Wonderland)

[81] The cause of this painful disease was first identified in Japan by Noboru Hagino. He discovered that its cause was the toxic cadmium (besides other pollutants) released into the Jinzu River from a mine and a smelter, the water from which was being utilized in various ways by local residents [Singh, 2005: p. 82].

1.1. THE MISRECOGNITION AND THEN RECOGNITION
OF THE HARMFUL EFFECTS OF LEAD AND MERCURY

1.1.1. Utilization of toxic heavy metals: their ‘rise and fall’

1.1.2. Exploring the harms of mercury

1.1.3. Lead additive in gasoline: “The mistake of the XXth century”

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the long-range transmission of toxic heavy metal pollution

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PROGRAMS AND AGREEMENTS

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covering, inter alia, toxic heavy metals

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1.4. WILL WE FINALLY ELIMINATE
THE USE OF TOXIC HEAVY METALS?

1.4.1. Differentiation in obligations and means of implementation

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of international programs and agreements

1.4.3. Actual trends in the use and
environmental releases of these toxic substances

1.4.4. The need to strengthen the science-policy interface

1.5. CONCLUSIONS AND LESSONS LEARNED

1.1. THE MISRECOGNITION AND THEN RECOGNITION OF THE HARMFUL EFFECTS OF LEAD AND MERCURY

1.1.1. Utilization of toxic heavy metals: their 'rise and fall'

Among the heavy metals, lead, mercury, cadmium, and their numerous compounds have been found to be particularly harmful to human health and the environment. Lead and mercury were used in many ways and for a very long time without their toxic effects being properly recognized. Mercury was sometimes called liquid silver, while cadmium and elemental lead are also silvery, so figuratively speaking, these three heavy metals and some of their compounds attractively 'shone' in many applications until their hazardous influences were clearly identified. This has led to their use being significantly restricted, and at least with mercury, to the development of a global agreement on the long-term phase-out of its mining and utilization.

Lead has been used since ancient times due to some of its favored properties (such as corrosion/rust resistance) and easy workability. Lead was mined in many places (primarily as galena or lead sulfide). This substance has also been experimented with in alchemy. Below, we mention just a few of its many forms of utilizations.

- Apart from its use in lead plumbing and lead vessels, perhaps the most controversial habit was heating wine in lead-lined pots in which a lead compound (lead(II) acetate) dissolved in wine made the drink tastier, sweeter, but actually poisonous. Some sources suggest that this widespread practice may have contributed to the decline of the Roman Empire [e.g., Gilfillan, 1965].[82] From the Middle Ages onwards, a wide range of other applications emerged: stained glass, ammunition, the lead letters used in letterpress printing, and lead-based rust-resistant paints, such as 'minium' (lead tetroxide or red lead), etc.
- The potentially adverse health effects of lead have been raised since antiquity, but it was not until the late 19th century that its health and environmental hazards began to be studied in depth, and even afterward, it took a long time to reach a scientific consensus on this matter [Needleman, 2004; Rosner, 2005; Riva, 2012[83]]. Only then did several countries begin to restrict at least some applications of lead, such as lead-based paints.
- Lead started a new 'career' in the first half of the twentieth century in lead-acid batteries and as an additive in gasoline (lead tetraethyl). This led to a rapid expansion in global lead production, followed by a temporary decline after some countries reduced and then eliminated the trade in leaded gasoline from the 1970s onwards. However, after the turn of the millennium, the demand for lead began to rise rapidly again, mainly due to the increasing production of lead-acid batteries [Mohr et al., 2018].

The mining and utilization of mercury dates back several millennia, and for a long time, this was done without any knowledge of its serious health impacts [Czaika & Edwards, 2014].

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[82] "We present here a completely new explanation for the Roman decay. It is derived […] from such firm sciences as toxicology, vital statistics, archeology, and evidence such as old bones and old Roman recipes and lead-lined pots for brewing poisons esteemed as delicious by the ancient well-to-do." (p. 53)

[83] "Lead poisoning is one of the earliest identified and most known occupational disease. Its acute effects have been recognized from antiquity when this condition principally afflicted manual workers and slaves, actually scarcely considered by the medicine of that time. The Industrial Revolution caused an epidemic of metal intoxication, urging scientists and physician of that period to study and identify specific symptoms and organ alterations related to chronic lead poisoning. During the 20th century, the acknowledgment of occupational and environmental toxicity of lead fostered public awareness and legislation to protect health." (p. 11)

- In ancient times, this metal was believed to be a panacea for maintaining health [Rustagi & Singh, 2010].[84] Its use as a dye was due to the reddish color of the mineral cinnabar (mercury sulfide). Later, mercury was applied in gold mining and panning (gold washing). Accumulating mercury contamination in the environment first became a serious problem in many parts of the world from these activities: the best-known example of this dangerous process is the California 'gold rush' that began in the mid-19th century. Gold particles were typically extracted from ores or sand using mercury, particularly during the process of artisanal and small-scale gold mining (ASGM). As a consequence, thousands of tons of toxic mercury were 'lost' into the environment in that region over a century and a half [Alpers et al., 2005; Solnit, 2006[85]].
- From the 18th century onwards, the demand for 'liquid silver' increased rapidly thanks to numerous inventions. Some typical ones include the following: (i) measuring, lighting, and other devices (thermometers, barometers; mercury vapor lamps, fluorescent tubes; the mercury oxide dry cell); (ii) pharmaceuticals and other chemical products (creams for skin diseases, ethylmercury-containing thiomersal for preserving vaccines, mercury-containing dental amalgams, and pesticides consisting of organomercury compounds) [Faragó, 2015]. Mercury is also well exploited in industrial processes: in the chlor-alkali industry for the production of chlorine for bleaching in the paper industry, as a mercury cathode for electrolysis, and in process of preparation of the feedstock (VCM) for PVC production.
- Inadvertent and intentional[86] releases of mercury (incl. its compounds) to the environment increased from the second half of the 19th century onwards, declined around World War II, and then rose again rapidly from the middle of the last century [Streets et al., 2019].[87] However, since the 1990s, the total amount of mercury from mining plus that recovered (recycled) from various applications and products has been halved. Mercury utilization has remained at rather high levels in artisanal and small-scale gold mining (ASGM), and currently, this is the main source of mercury pollution [UNEP, 2006[88]; UNEP, 2013].
- Mercury, other heavy metals, and hazardous substances may also cause serious transboundary problems induced by industrial accidents, as occurred along the Rhine in 1986 and the Tisza River in 2000 [Schwabach, 1989[89]; Faragó & Kocsis-Kupper, 2000, 2001; Katona, 2021[90]]. Such incidents have catalyzed the reinforcement of international cooperation and regulation in this field.

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[84] "Elemental mercury was known to the ancient Greeks, Romans, Chinese, and Hindus. Each civilization had its own legends about mercury, and it was used as everything from a medicine to a talisman." (p. 45)

[85] "During the California Gold Rush, an estimated 7,600 tons or 15,200,000 pounds of mercury were thus deposited into the watersheds of the Sierra Nevada. The U.S. Geological Survey estimates that placer, or stream-based, mining alone put ten million pounds of the neurotoxin into the environment, while hard-rock mining accounted for another three million pounds. Much of it is still there".

[86] Intentional releases are primarily related to the spraying of mercury-based pesticides.

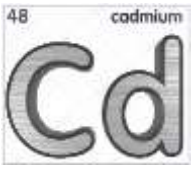
[87] "After 1950 there was a dramatic increase in Hg releases due to the post-war economic boom. This continued until 1970, when preventative measures began to be introduced […]. The decline in global Hg releases continued after 1970, but may have ended shortly before 2010, as gains from the removal of Hg from commercial products lessened". (p. 420)

[88] "Largely as a result of increasing awareness and regulation, the global demand for mercury has declined from more than 9,000 metric tonnes annual average in the 1960s, to just under 7,000 metric tonnes in the 1980s, and less than 4,000 metric tonnes since the late 1990s. In 2005, global demand for mercury, on the strength of high gold prices and related strong mercury demand for artisanal and small-scale gold mining, remained in the vicinity of 3,000-3,900 metric tonnes per year". (p. 55)

[89] "The chemicals that washed into the Rhine at Schweizerhalle formed a red toxic trail 70 kilometers long, moving downstream at 3.7 kilometers per hour. […] Swiss officials later stated that about 200 kilograms of mercury had washed into the river […]. A later estimate put the amount of mercury at two tons." (p. 446)

[90] "As it was proven by the cyanide and heavy metal contamination in the year 2000 on the River Tisza, the problem of environmental pollution cannot be solved within the traditional (modern) framework of nation-state sovereignty. For the solution of an environmental crisis, the limitation of nation-state sovereignty and a new type of international cooperation would be needed that takes ecological aspects into consideration." (pp. 5-6)

- Mercury's adverse effects on human health and the environment have been verified with increasing certainty since the middle of the last century. Only since then did its use start to be progressively restricted.



Cadmium was only discovered in the early 19th century. Two scientists almost simultaneously identified this metal during their laboratory experiments.[91] Thanks to some of its beneficial properties, it has found a wide range of applications.

- The best-known cases of its use are in alloys, anti-corrosion metal coatings, solders, paints (cadmium sulfide, cadmium selenide), and nickel-cadmium batteries. The latter currently accounts for almost four-fifths of all cadmium use.
- From the mid-20th century onwards, demand for cadmium increased at a fast pace and, in parallel, the total amount of cadmium mined (mainly as a 'by-product' of zinc mining and processing) refined and later recycled also increased until the turn of the millennium [UNEP, 2010].
- The detrimental effects of cadmium were first encountered during a mass poisoning in Japan in the 1960s in the area of the Jinzu River, whose water, used for irrigation, was contaminated with this toxic substance from a mine and metal foundry [Singh, 2005; Aoshima, 2016]. Cadmium has similarly caused severe problems elsewhere, for example, when this substance entered the water of the Rhine River [Jolánkai et al., 1993]. The health and environmental hazards of this metal and its compounds began to be thoroughly investigated in the 1970s [Fleischer et al., 1974[92]; Hiatt & Huff, 1975; Carruthers & Smith, 1979]. This allowed for a complete understanding of the noxious consequences, also based on much more extensive monitoring data and analysis [WHO/IPCS, 1992a, 1992b; UNEP, 2010], including the clarification that: "Cadmium is toxic at very low exposure levels and has acute and chronic effects on health and environment." [NCM, 2003]

Arsenic is 'only' a metalloid, but because of its toxicity, it is sometimes referred to along with the toxic heavy metals, that is, lead, mercury, and cadmium.

- The dangers of arsenic have been known for a long while: inhaling 'arsenic fumes', ingesting accidentally or on purpose arsenic poison (arsenic trioxide), and administering it with malicious intent to somebody (!).
- Its compounds (e.g., arsenic sulfide) have been and are still used in several ways [Holmyard, 1931; Tchounwou et al., 2012].

[91] Cadmium was discovered by Friedrich Stromeyer in 1817 and only a few months later by Karl Hermann in 1818, who published some details of this discovery and also correctly cited Stromeyer's research [Hermann, 1818].

[92] "Cadmium was recognized many years ago to be a highly toxic element, and the need for precautions in industrial operations in which workers were exposed to dusts and vapors of the element or its compounds had long been known. It was not, however, until comparatively recently that concern began to be expressed over the possible effects on human health of exposure over long periods to low concentrations of cadmium, in part because of its steadily increasing consumption and consequent increase in the general environment". (p. 254)

1.1.2. Exploring the harms of mercury

> It is almost unbelievable how much time passed until the harmful effects of mercury and its compounds on human health and the biosphere became clearly established in the middle of the 20th century. It is almost incomprehensible because, in some long-ago publicized occurrences, the mercury-related direct cause of a severe illness was rather obvious. For example, we can refer here to the incident in 1810 when mercury under transportation on a British ship was spilled, leading to the grave sickness of the crew [Burnett, 1823].[93] Signs of mercury poisoning were not registered and analyzed even in places where many people came into close contact with this toxic substance (e.g., miners, gold diggers, and gold panners), and the health-damaging consequences could have been easily detectable.

Noxious mercury. In the following cases, the approximate amount of a mercury compound in the body of persons who ingested that substance and the symptoms of the illness they experienced were systematically recorded. These were the first occasions when mercury poisoning was definitely diagnosed, and in turn, led to the beginning of the worldwide monitoring and investigation of this issue. In other words, these fatal occurrences were turning points in the history of mercury's applications and in comprehending its threat to health and the environment.

- In the Japanese seaside town of Minamata, at the Chisso Corporation's chemical factory, mercury sulfate was applied as a catalyst for producing acetaldehyde, a chemical used for manufacturing plastics, cosmetics, and pharmaceuticals, from the 1950s onwards. The industrial effluent contaminated by the particularly noxious organic mercury compound (methylmercury) from this factory was discharged into Minamata Bay. These toxins accumulated in fish and other marine organisms, and the residents who fed on them developed symptoms of mercury poisoning. Since the mid-1950s, thousands of inhabitants in that region have been diagnosed with neurological and musculoskeletal disorders, and around 600 deaths have been recorded. During 1959-1962, researchers at a Japanese university (Kumamoto) revealed that the substance mentioned above was the cause of this 'Minamata disease', but the company denied responsibility and did not publish the results of its own tests [Hachiya, 2006].[94] Acknowledgment of liability was clearly hampered by the latter's insistence on continuing with production in the same manner,[95] which was in the economic interests of the company [Amasawa et al., 2016[96]]. Finally, a lengthy expert and judicial process established the causal link between the toxic technology and the mass disease outbreak, obliging the company to pay compensation to the victims (or their families) and abandon the mercury-based procedure [MoE, 2002]. In the mid-1960s, another Japanese company (Showa) turned out to be in a similar situation. Its executives denied that the industrial wastewater discharged from their chemical plant into the nearby river had caused the poisoning of hundreds of people and pointed to another possible source of mercury pollution. This 'second Minamata case' also ended with the dismissal of the misleading arguments, i.e., with convincing counterevidence [Harada, 1972].

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[93] "The heat of the weather was at this time considerable, and the bladders, having been wetted in the removal from the wreck, soon rotted, and the mercury, to the amount of several tons, was speedily diffused through the ship […]. In the space of three weeks from the mercury's being received on board, two hundred men were afflicted with ptyalism, ulcerations of the mouth, partial paralysis in many instances, and bowel complaints." (p. 403)

[94] "A Chisso engineer successfully isolated methylmercury in the waste from the acetaldehyde synthetizing process of the factory in 1961. However, the company did not release the findings. In the following year, the isolation of the methylmercury was published by members of the Kumamoto University Research Group […] from not only the shellfish in the Minamata Bay but also the sediment of the bay." (p. 115)

[95] In general, this phenomenon is called 'technological inertia' or 'technological lock-in'.

[96] "During the post-war rebuilding years, the production of materials such as polyvinyl chloride was important, and Chisso switched […] to the established commercial method […] in order to increase the production output. This method required the use of another oxidizing agent […], producing even more methyl mercury in the process". (p. 98)

- The mercury poisoning of numerous residents in Iraq in the early 1970s also catalyzed the recognition of the dangers posed by this and other toxic chemicals and the development of international cooperation on the subject. The grain seeds ordered from abroad by the Iraqi government were coated[97] with a fungicide containing mercury compounds. However, some of the seeds were not sown but were used by those to whom they were distributed in the baking of bread. Even basic precautions were not taken, such as informing the population about the risk of poisoning. Thus, many people were exposed to significant doses of mercury. More than six thousand cases of the disease were recorded, with over four hundred deaths. WHO experts were involved in the medical examinations, and the findings became crucial to understanding the mechanism of the poisoning (by analyzing the patients' mercury load level and pathological symptoms) [WHO, 1976; Skerfving & Copplestone, 1976[98]; Takizawa, 2009].

Extensive observations and analyses have confirmed the harms attributable to mercury and its compounds stemming from their uses and environmental releases over the past decades [WHO/IPCS, 1989; UNEP/GMA, 2002; Tchounwou et al., 2003; Greer et al., 2006; WHO, 2007]. We highlight findings from two recent studies that illustrate why and how difficult it is to eliminate this serious problem.

- "Mercury is a ubiquitous environmental toxin that causes a wide range of adverse health effects in humans. […] Readily absorbed after its inhalation, mercury can be an indoor air pollutant, for example, after spills of elemental mercury in the home; however, industry emissions with resulting ambient air pollution remain the most important source of inhaled mercury. Because freshwater and ocean fish may contain large amounts of mercury, children and pregnant women can have significant exposure if they consume excessive amounts of fish" [Goldman et al., 2001: p. 197].
- "Despite decades of scientific research and policy actions to control mercury, exposure to toxic methylmercury continues to pose risks to humans and the environment. […] Mercury-related research is carried out over a range of disciplines, including chemistry, biology, toxicology and public health. Regulatory agencies at a variety of different political scales have developed mercury policies over time in the context of increasing scientific knowledge of processes in the environment and ecological and human effects. Yet, environmental problems remain." [Selin, 2011: p. 2394]

1.1.3. Lead additive in gasoline: "the mistake of the XXth century"

> The utilization of lead is very ancient, and although some adverse side effects have long been noted, they did not seem to be well established or widespread, while the metal has been shown to be very useful. It was not until the beginning of the twentieth century that sufficient knowledge was available about the health hazards of lead ingested directly (e.g., through drinking water) and its negative ecological influences. This led to the gradual restriction and elimination of some applications and the manufacture of certain devices containing lead or lead compounds.

The use of lead tetraethyl as an 'anti-knock' additive in gasoline increased rapidly from the 1920s onwards. However, the resulting air pollution and its health-damaging consequences were considered negligible for a long time compared to the benefits concerning motor vehicle engines.

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[97] This procedure is also called 'seed dressing'.

[98] "Between 15 September and the first week of December 1971, 73 000 t of wheat and 22 000 t of barley, treated with organomercury seed dressing agents, were distributed in Iraq. The seed was intended for planting but, owing to a series of unfortunate circumstances, an unknown quantity of the wheat was used by a farmer for making bread […]. It can therefore safely be concluded that the only important exposure to mercury was through bread, and that the mercury was in the form of methylmercury. […] a dose-response relationship existed between the intake of contaminated loaves and the prevalence of symptoms and signs". (pp. 102-103)

- In the 1960s, German experts drew attention to the potential threat, while the French claimed that no health or environmental risk was associated with these emissions: "Lead, in particular, added to gasoline for its anti-knock properties, was perceived as a health threat at this time, given new evidence of its neurotoxicological effects, which are especially severe in children. After lead-based paint and lead solder in water pipes and food cans was prohibited, gasoline lead – tetraethyl and tetramethyl lead additives – became the next target. […] A preliminary analysis of newspaper coverage shows that gasoline lead-induced health risks were first reported in the German press in the 1960s. Articles in the British press focused not on lead, but on urban smog. And in 1972, a group of French government experts did not acknowledge that any automobile emissions were dangerous" [Storch et al., 2002: p. 394]. Nevertheless, in the 1970s, a (West) German regulation already required a reduction in the concentration of lead additive in gasoline (from 0.6gPb per liter to 0.4gPb and later to 0.15gPb).
- At the same time, in the USA, there were heated polemics between Clair C. Patterson, an independent geochemical expert who warned of severe effects, and Robert A. Kehoe, a toxicological expert (hired by the company involved in the production of the lead additive), who stated that those emissions were harmless [Needleman, 2000]. Patterson cited concrete data indicating that urban residents had high blood lead concentrations, obviously due to breathing in lead-contaminated air [Patterson, 1965].[99] Kehoe's counter-argument was that humans are accustomed to the same relatively low levels of lead in the environment, which is of natural origin ("humans have achieved a biological adaptation to lead"). Patterson considered this claim to be completely unfounded.[100] We might call his adamant rejection a form of 'eppur' reasoning, following a saying attributed to Galileo Galilei[101] – i.e., that stubborn facts must be respected, and other debate partners must be convinced based on the latter [Faragó, 2018a]. This debate about health and ecological aspects continued over a long period, beginning with a Senate committee hearing in 1966 and then with the participation of the representatives of the newly created Environmental Protection Agency (EPA, 1970-).

The growing body of evidence about the harm caused by lead additives led to a reduction in claims that these effects were unfounded and that reducing the production and sales of lead additives would result in serious economic losses.

- As a precautionary measure, a gradual reduction of the specific content of the lead additive in gasoline began in the USA. The turning point in this process was the aforementioned 1966 hearing, which finally resulted in the banning of leaded gasoline after three decades (!), that is, in 1996 [EPA, 1996].
- Since the 1970s, the use of this additive was first restricted and then eliminated in several other countries. This was promoted by the fact that the catalytic converters ('cats') for reducing the emissions of other pollutants (such as carbon monoxide) from motor vehicles were being developed at that time, which (i.e., the 'cats') would have been destroyed by that lead compound [Salma, 2010].[102] To characterize the significance of the matter, Carl M. Shy gave this title to an

[99] "[U]ses of leaded pigments and cosmetics are acts equivalent in toxicological function to the more sophisticated acts of using leaded gasolines and insecticides. The term natural should not be applied to concentrations of lead in any substance occurring in any society that utilized lead metallurgy […]. The industrial use of lead is so massive today that the amount of lead mined and introduced into our relatively small urban environments each year is more than 100 times greater than the amount of natural lead leached each year from soils by streams and added to the oceans over the entire earth." (p. 344)

[100] "Kehoe displayed the second part of this basic argument: humans have achieved a biological adaptation to lead. Patterson's precise point was that human's exposure to lead was new, and that a few thousand years of lead exposure, a Darwinian moment, was nowhere near the time needed to develop adaptive responses." [Needleman, 2000: p. 27]

[101] "Eppur si muove!"

[102] "The platinum metals in the catalyst are in the order of tenths to tens of grams. In order to maintain efficiency, the lead addition to petrol had to be eliminated, because the lead halide aerosols from leaded (and brominated) fuel were coating the catalyst's useful surface area, i.e., acting as a catalyst poison." (p. 293)

article of his in a WHO publication: “Lead in the petrol: the mistake of the XXth century” [Shy, 1990].

- This paradoxical situation also provided a more general lesson. Indeed, one of the findings of the first court judgment in this case (which came into force in 1976) was that: “Man’s ability to alter his environment has developed far more rapidly than his ability to foresee with certainty the effects of his alterations” [Hoban & Brooks, 2018].

1.1.4. Environmental releases and the long-range transmission of toxic heavy metal pollution

This problem has become globalized as the utilization of these heavy metals and their compounds has spread worldwide, and the resulting toxic pollutants have been able to travel over very long distances in the environment.

The emission of lead and cadmium pollutants is mainly caused by human activities, and these pollutants can cause serious harm far from their sources.

- The sources and levels of anthropogenic emissions of these substances have changed substantially since the early decades of the past century. For a long time, the transport sector was a major source of lead pollution (owing to the lead additives in gasoline mentioned above), besides some industrial activities, including metallurgy. The latter is also a considerable source of cadmium pollution [NCM, 2003[103]; Poikolainen et al., 2004[104]; Bozó, 2005]. Considerable amounts of lead and leaded materials were dumped in landfills, especially in developed countries, after strict regulations were introduced to reduce the use of this toxic metal and its compounds. A vivid example of this is provided by a Dutch survey, which found that more than a tenth of the 80,000 tons of lead used there in 1990 ended up in landfills or were discharged into the environment [COWI, 2002].[105] Elsewhere, landfills have contributed significantly to environmental pollution through the release of heavy metals and other harmful substances [Rodriguez-Eugenio et al., 2018].[106] Especially in view of their health effects, the measurement of the environmental concentrations of these pollutants and the study of their transmission has been ongoing in several countries, including Hungary, since the 1980s [Mészáros et al., 1988[107]; Bozó et al., 1992].

[103] “The dominant sources of atmospheric emission will vary depending on the region or country considered. Non-ferrous metal production as well as combustion of coal and oil and waste incineration should be considered important sources. […] According to the assessment, by far the major source of cadmium emission to the air is non-ferrous metal production. The estimates should, however, be treated with caution as some sources may be significantly underestimated due to the methodology of the inventories. In particular waste incineration may be underestimated”. (pp. 3, 8)

[104] “Most of the Cd that is released into the atmosphere originates from the processing of iron ore and, in smaller quantities, from the burning of fossil materials and waste. The most important emission source of Pb is vehicle traffic, other emission sources including the metal industry and mining activities. During the last two decades, lead emissions from traffic have decreased considerably, especially in Europe and North America. This has been due to the introduction of unleaded petrol […]. Lead occurs primarily in the atmosphere in elemental form as aerosol particles or as a number of chemical compounds. In the atmosphere Cd is also primarily attached to aerosol particles”. (p. 292)

[105] “Of the total turnover of about 80,000 tonnes lead […] 12,400 was accumulated in landfills and residues used for construction work or discharged to the environment.” (p. 29)

[106] “[M]any pollutants, such as heavy metals, polyaromatic hydrocarbons, pharmaceutical compounds […] from landfill leachates that may be polluting soil and under groundwater, or by ash fallout from incinerating plants”. (p. 24)

[107] “High concentrations of lead and cadmium in air and soil have been shown to have adverse effects on the biosphere and human health. Concentrations of these metals are therefore monitored in many parts of the world, both in urban areas and in rural or background areas far from the sources of pollution. In 1981 such a monitoring program was also launched in Hungary”. (p. 134)

- These pollutants are predominantly transported by aerosol particles hundreds of kilometers from their emission sources during their atmospheric residence time of several days (on average) before being deposited on the surface [Bozó, 1996[108]; Salma, 2010; UNEP, 2010[109]].

The sources of mercury pollution. In addition to emissions from natural sources (e.g., volcanic activity), mercury-related pollutants have been and are still being released into the environment (atmosphere, water bodies, land surface, and soil) in large quantities from various applications, their waste and its incineration, and some other human activities.

- While coal usually contains this toxic metal only in trace concentrations, the atmospheric mercury emissions from coal combustion, in particular from coal-fired power plants in many countries, are far greater than the total emissions from mercury-containing products, waste, and industrial processes that use mercury and mercury compounds [Rallo et al., 2012].[110] Added to these sources is mercury pollution, e.g., from iron production, metallurgy, cement production, and the glass industry, which is the side effect of these activities.
- It is estimated that, in 2010, nearly 2,000 tons of mercury were released into the atmosphere from human activities globally; however, more than a third of this was from artisanal and small-scale gold mining (ASGM) [UNEP/GMA, 2013; UNEP/TK, 2013]. The direct mercury contamination of water bodies (i.e., excluding atmospheric deposition) was nearly 200 tons in the same year.

Mercury pollutants in the atmosphere can cover even transcontinental distances. Their effects are especially hazardous in the case of their deposition in water bodies, where they are converted into highly toxic organic methylmercury.

- The atmospheric transmission of these pollutants was first studied in the late 1970s based on the measurements conducted in Sweden. Cyrill Brosset examined mercury concentrations in air and precipitation as a function of altimetric wind data and in areas away from local emission sources, moreover, in the waters of some lakes [Brosset, 1982].[111] At the same time, the environmental cycle of mercury in general was also the subject of research, including its natural and anthropogenic sources and biogeochemical processes [Nriagu, 1979; Andren & Nriagu, 1979]. The systematic analysis of the long-range (incl. continental scale) atmospheric transport of some air pollutants was made possible by the European Monitoring and Evaluation Programme (EMEP) established in the 1970s, but the monitoring, numerical modeling and assessment of the release

[108] "It can be concluded from the measurements and model calculations that the atmospheric concentration and deposition of Pb and Cd in rural areas of Hungary are greatly affected by sources hundreds of kilometers far away from the receptor area." (p. 49)

[109] "93. Specific evidence of cadmium intercontinental transport is very scarce. Due to the relatively short residence time of cadmium in the atmosphere (days or weeks), the airborne dispersion of cadmium has a pronounced local or regional character. However, data from ice core measurements in Greenland indicate that cadmium can be transported over distances of up to thousands of kilometers."

[110] "[F]ossil fuel-fired power plants are the largest sources of mercury released into the atmosphere. It is essential to control these emissions at all levels – global, regional, and local – in order to achieve reductions in global anthropogenic emissions […]. There is abundant evidence that mercury and its compounds are highly toxic to humans, ecosystems, and wildlife. Research and monitoring over the years have provided ample justification for the need to taking measures to reduce mercury emissions from coal-fired power plants which is the main source of such emissions in many countries." (pp. 1090, 1095)

[111] "It is shown that the total Hg in air may be divided into two fractions. The most important one may be considered to be a background and is probably the result of re-emission of Hg by the ground and by natural water. The other fraction is highly dependent on wind direction in the same way as black particles. This fraction seems to be of anthropogenic origin. […] In some of these lakes the Hg is known to be introduced by local industries. However, there are many other lakes situated far from any anthropogenic Hg source still showing up high Hg content in fish." (p. 37)

into, transmission in and removal of toxic heavy metal pollutants from the atmosphere has only been carried out since the 1990s [Haszpra, 2008[112]; Tørseth et al., 2012].

- These measurements and investigations established that while gaseous elemental mercury (elemental mercury vapor) remains in the atmosphere for an average of six months to two years, the much smaller amounts of gaseous reactive mercury compounds and aerosol-bound mercury pollutants only remain in the atmosphere for a few days [Butler et al., 2007; Wängberg et al., 2001]. Due to the long atmospheric residence time of gaseous elemental mercury (Hg(0)), it can travel very long distances in the air, and this is why the effects of this toxic substance have been detected in regions very far from its emission sources.
- Following a thorough exploration of the European continental scale transport of this air pollution, it has been suggested that these pollutants may cover much greater distances and travel thousands of kilometers in the atmosphere between continents. In this regard, the atmospheric transport of such pollutants, above all from Asian emission sources, has been extensively studied [Weiss-Penzias et al., 2007[113]; UN, 2011; CLRTAP, 2012]. This has become a major international environmental protection, health, and political issue because, although appropriate measures have led to a marked reduction in mercury emissions in Europe and North America, there have been significant increases in such emissions in some Asian countries (mainly in China and South Korea), primarily due to the intensifying production of PVC and coal combustion. A recent report pointed clearly to this increase [UNEP/GMA, 2019].[114] Consequently, first of all, in connection with coal combustion, it would be advantageous to reduce mercury emissions in addition to emissions of carbon dioxide. This could contribute to implementing the 2015 international agreement on climate change and the 2013 convention on mercury, particularly by China [Mulvaney et al., 2020]; the achievement of these 'double environmental benefits' would obviously also apply to many other countries.

* * *

The thorough exploration and verification of the toxic influences of mercury and mercury compounds, as well as the anthropogenic sources of releases of mercurial pollutants into and their transmission in the environment, is an extremely lengthy and instructive story. Similarly, lead was utilized in many different ways for so long without any attention being paid to its injurious consequences. Finally, researchers revealed all the essential properties of mercury, lead, and cadmium, and relying on this knowledge, the process of eliminating the uses and harms of these toxic heavy metals could begin. In the following, we present and assess the global dimensions of this problem and developments in international cooperation, then highlight the key lessons that can be drawn and generalized from these.

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[112] "In Phase 6 (1995-1998), an attempt was made to make the measurement of certain heavy metals and hydrocarbon compounds mandatory, but with only limited success. Only the most important heavy metals (lead, cadmium) were included in the mandatory measurement program. […] Since 2006, we have also been reporting the concentrations of the two most important heavy metals (lead and cadmium) in precipitation and aerosol to the EMEP data center, thus essentially fulfilling the measurement program of a category 1 monitoring station." (pp. 10, 12)

[113] "Total airborne mercury (TAM) and carbon monoxide (CO) were measured in 22 pollution transport 'events' at Mt. Bachelor Observatory (MBO), USA […] emissions from Chinese anthropogenic, global biomass burning, and global boreal biomass sources in order to estimate the emissions of gaseous elemental mercury (GEM) from these sources. The GEM emissions that we calculate here are: Chinese anthropogenic (620±180 t/y), global biomass burning (670±330 t/y), and global boreal biomass burning (168±75 t/y) […]. Chinese GEM emissions from this study are higher by about a factor of two, while our estimate for global biomass burning is consistent with previous studies." (p. 4366)

[114] "The domestic shares in anthropogenic deposition show an increase since 2010 in East Asia (from 76% to 77%) and South Asia (58% to 66%), which is explained by the increase in Asian anthropogenic emissions since 2010." (p. 27)

1.2. INTERNATIONAL SCIENTIFIC COOPERATION

Cooperation between the representatives of relevant scientific disciplines and organizations has become essential in studying and discovering the complex health and environmental influences of the widespread use of toxic heavy metals. Furthermore, this collaborative process has played a significant role both in finding solutions for avoiding or at least limiting these dangerous human activities and facilitating the development of international policy programs and agreements to address them.

1.2.1. Studies and research programs under the aegis of UN agencies

Increasing attention to the adverse effects of heavy metals. From the early 1970s onwards, expert groups convened and supported by some UN specialized agencies began to analyze more closely the health and environmental hazards caused by these chemicals. Their interest was initially sparked primarily by the incidence of mercury poisoning in Iraq and the ongoing debate about the injuriousness of lead additives in gasoline.

- It is noteworthy that food safety, associated with an increasing diversity of additives and food contaminants, including toxic heavy metals, had already been on the agenda of FAO and WHO since the late 1950s (thus well before, for instance, the above-mentioned Iraqi poisoning affair). Regarding the health issues related to these substances, the experts from these organizations highlighted the severe risks and the need for more in-depth investigations, including into the sources of these chemicals and the options for reducing their environmental releases [FAO/WHO, 1972].[115] (The experts from these UN agencies drew these conclusions at a meeting held in April 1972. The representatives of the UN Environment Programme could join this institutional collaboration only later for a simple reason: the decision on the establishment of that new institution was made at the UN Conference on Human Environment in June of that year.)
- The WHO specialists were invited to take part in the exploration of the causes of the above-mentioned Iraqi poisoning case, and their preliminary results were presented at an international forum in 1974 [WHO, 1976].[116] The first volume of the *Environmental Health Criteria* series on the harms of mercury and its compounds had been compiled and issued with the joint support of UNEP and WHO [WHO/IPCS, 1976].
- As concerns lead-using applications, such as leaded gasoline in motor vehicles, research activities on the potential harms accelerated, and on the basis of their outcomes, technical information materials and recommendations were published [WHO, 1969; WHO/IPCS, 1977]. The first such surveys on cadmium were completed much later [WHO/IPCS, 1992a; WHO/IPCS, 1992b].

[115] Joint FAO/WHO Expert Committee on Food Additives: "FAO and WHO should promote and where necessary coordinate research designed to extend knowledge about the toxicity of mercury, lead and cadmium […] In view of the seriousness of the problem of environmental pollution by mercury, lead and cadmium and its implications for human health and food supply, the Committee recommends that: (1) all possible steps be taken to reduce such pollution". (p. 29)

[116] "The main findings of this research were discussed at the Conference on Intoxication due to Alkylmercury Treated Seed, held in Baghdad from 9 to 13 November 1974. The Conference was organized by WHO and was attended by participants and observers from over 20 countries. The involvement of WHO in a poisoning outbreak also means that steps can be taken on an international level to prevent similar outbreaks in the future. The Organization's many close contacts with other international organizations lead to a consideration of the global problems raised and to recommended courses of action to solve them."

- In the 1970s, WHO working groups were set up to assess the mercury and lead-induced health problems, followed sometime later by another one tasked with analyzing the risks posed by cadmium,[117] such as its carcinogenicity [WHO/IARC, 1976].

The environmental dimension of the utilization of these substances was primarily taken care of by the United Nations Environment Programme (UNEP) from the mid-1970s onwards. This covered assessments of the main properties of these toxic metals and their compounds, estimates of their presence in the environment, identification of the sources, and exploration of possible harms caused by them. These studies were fulfilled as part of the Global Environmental Monitoring System (GEMS)[118] and all information thereby collected was recorded in and made freely available from the International Register of Potentially Toxic Chemicals (IRPTC) [UNEP, 1980; UNEP, 1982].

- Proposals by the advisory bodies on lead and mercury, and later on, cadmium, were approved by the UNEP's decision-making council [lead: UNEP, 1977; UNEP-MARC, 1980; mercury: UNEP-MARC, 1981; cadmium: UNEP-MARC, 1982]. Subsequently, this organization became even more active in monitoring the extraction and use of these heavy metals, as well as the resulting environmental pollution and its consequences.
- The first *Global Mercury Assessment* [UNEP/GMA, 2002] clearly exemplified the strengthening of institutional cooperation in response to growing concerns about hazards stemming from mercury. The more recent and updated version of this report was published in 2019 and revealed that lead- and cadmium-related matters and their analysis were proving to be even more complex for several reasons (including the considerable differences in this regard between many developed and developing countries). This foreshadowed that a global agreement on the reduction/elimination of the use and harmful influences of these toxic substances would not be possible in the future, but only at a pan-European level.
- Under the auspices of UNEP, comprehensive reports such as the *Global Environmental Outlook* (GEO) and the *Global Chemical Outlook* (GCO) were prepared, which covered not only the problematics related to mercury but also those regarding lead and cadmium.

Expanding cooperation. In addition to the WHO and UNEP, other organizations became involved in the exploration of the environmental releases and various effects of these substances.

- Toxic heavy metals were also examined within the International Programme on Chemical Safety (IPCS) coordinated by WHO and UNEP, in which experts from the International Labour Organisation (ILO) participated as well. One of the outstanding products of this program is the INCHEM database of publications, which contains a large body of information on scientific literature sources about mercury, lead, and cadmium, besides many other chemicals. With joint WHO and FAO support, work continued to assess the agricultural issues and food safety in relation to these toxic materials. Partly connected to these studies, researchers commissioned by the World Meteorological Organization investigated the atmospheric transport of these pollutants, their deposition to and concentrations near the surface. The effectiveness of these activities was facilitated by the establishment of the Background Air Pollution Monitoring Network (BAPMoN) in the late 1960s, which collected measurement data on an increasing number of atmospheric pollutants.
- An even more wide-ranging inter-agency program was launched in 1995 to promote the sound management of chemicals (IOMC).[119] This program went beyond considering emission sources

[117] WHO: Working group on heavy metals, Task group on environmental health criteria for mercury, Task group on environmental health criteria for lead, Task group on environmental health criteria for cadmium.
[118] The 'EarthWatch' concept was the basis for the development of this comprehensive monitoring system.
[119] Inter-Organization Programme for the Sound Management of Chemicals (UNEP, ILO, WHO, FAO, UNIDO, UNITAR; OECD).

and adverse effects (inter alia, regarding toxic heavy metals) and aimed to create a more solid scientific basis for appropriate policies and measures.

- As a follow-up to recommendations on chemicals and wastes adopted in the 1992 global sustainable development agenda, a new organization, the Intergovernmental Forum on Chemical Safety (IFCS), was established on the joint initiative of UNEP, ILO, and WHO [UN, 1992].[120] Under the aegis of this Forum, an overarching strategy for sustainable chemical management (SAICM) was developed and approved in 2006, which addressed, among other topics, hazards and safety-related issues concerning toxic heavy metals.
- Based on more and more observational and research-based information, along with the recommendations made by the experts participating in the above-mentioned programs and forums from the 1970s onward, it became clear that these heavy metals and their compounds are highly dangerous to health and the environment. First of all, WHO and UNEP supported these activities and the communication of their outcomes.[121] It also turned out that there was not yet sufficient data and knowledge about the mechanisms and magnitudes of anthropogenic releases and the adverse effects of these pollutants, moreover, – especially because of the international relevance – about their long-range transmission and long-term accumulation in the environment [WHO/IPCS, 1976[122]; WHO/IPCS, 1977[123]].

1.2.2. Other international organizations and networks

International research cooperation has played an important role not only in strengthening the theoretical foundations of chemical safety in general but also in supporting the determination and implementation of actions aimed at tackling, e.g., the problems caused by toxic heavy metals. In this way, the participants of scientific bodies and gatherings have also contributed to setting intergovernmental policy and legal instruments regarding these matters, even if, in many cases, the concrete goals and provisions of the latter have been substantially less ambitious than those contained in the science-based recommendations.

- An environmental science committee was set up in 1969 within the International Council of Scientific Unions that also dealt with the hazards attributable to these heavy metals (ICSU-SCOPE).[124] The beginning of the exchange of ideas regarding these investigations was marked by a conference in 1975 entitled ‘Heavy Metals in the Environment’

[120] *Agenda 21*, adopted in 1992, addressed the adverse health and environmental effects of toxic chemicals and hazardous waste and also presented the necessary responses (chapters 6, 9, 19-21). That document explicitly referred to the health risks and emission reduction challenges associated only with lead among the toxic heavy metals we discuss here (6.41). This could be because the problem of lead, and in particular ‘leaded gasoline’, was then already well known, while the international community was very divided about the hazards of mercury applications, and the potential harms of cadmium had hardly been noticed at that time.

[121] Hg: [IPCS, 1976, 1990; UNEP-MARC, 1981; WHO, 2003, 2007]; Pb: [IPCS, 1977; UNEP, 1977; UNEP-MARC, 1980]; Cd: [UNEP-MARC, 1982; IPCS, 1992a, 1992b].

[122] 1.2.3 Environmental distribution and transport “Two cycles are believed to be involved in the environmental transport and distribution of mercury. One is global in scope and involves the atmospheric circulation of elemental mercury vapour from sources on land to the oceans. […] The other cycle is local in scope and depends upon the methylation of inorganic mercury mainly from anthropogenic sources. Many steps in this cycle are still poorly understood”.

[123] 4. Environmental transport and distribution “From a mass-balance point of view, the transport and distribution of lead from stationary or mobile sources into other environmental media is mainly through the atmosphere. […] The mass transfer of lead from air to other media is as yet poorly defined and the various mechanisms involved in the removal of lead from air are not fully understood. […] Much remains to be learned about the environmental transport and distribution of lead.”

[124] SCOPE: Scientific Committee on Problems of the Environment (1969-); The International Council of Scientific Unions (ICSU) became the International Council for Science (ISC) in 2018 after the merger of the ICSU and the International Social Science Council (ISSC).

held in Toronto [Hutchinson et al., 1975]; in 2020, the 20th such event was organized that year in Seoul.

- At another conference convened in New Zealand in 1984, participants argued that assessing the threats of these metals to ecosystems was at least as important as understanding their effects on human health [Hughes, 1985].[125] At a more recent meeting in Toronto, it was raised, among other things, that there were obstacles to more comprehensive studies of the environmental transport of heavy metal pollution, primarily due to the scarcity of observational data from developing countries [Hutchinson & Meema, 1987].[126] This also foreshadowed that about a decade later, an agreement on these toxic chemicals could only be reached at a pan-European level (i.e., under the framework of the UNECE).

Stakeholders' organizations

- With the support of UNEP, an international partnership was formed in 2002 with the objective of promoting the transition to "clean fuels and vehicles" and eliminating the use of leaded gasoline worldwide (PCFV).[127] A few years later, the UNEP and WHO helped create a global coalition that pushed for the phase-out of lead-based paints (LPA, 2009-).[128]
- The international civil organization BMWG, founded in 2002, advocated for a ban on the use of mercury as soon as possible and it continued its activities from 2005 onwards within a broader setting for achieving the 'zero mercury' goal (ZMWG).[129] In 2007, UNEP initiated the formation of a global network of scientific, industrial, and civil society organizations for the minimization of anthropogenic mercury emissions.[130] Also noteworthy is the work of a group of metal mining companies that are committed to adhering to sustainability principles and a specific code of practice for mercury (ICMM).[131]

* * *

It took about a decade and a half for intergovernmental policy discussions to begin, even after a considerable amount of knowledge was already available from observations, diverse scientific analyses, and expert recommendations on the use of these heavy metals and options for mitigating their harmful effects. An important 'bridge' between science and policy became the World Commission on Environment and Development, established in 1983, which, in a comprehensive report, pointed to the need to shift to safer practices concerning these heavy metals due to their serious health and environmental influences [WCED, 1987]. In the global agenda for the 21st century, adopted in 1992, detailed chapters were devoted to actions associated with chemicals and waste, with the general objective that risks arising especially from the toxic components of these substances be urgently reduced [UN, 1992: par. 19.48]. The whole problem of toxic heavy metals was not raised either then or at the 1994 session of the UN commission established to facilitate the implementation of that global agenda, but at least the consensus was achieved that the health and environmental hazards caused by lead (e.g., by pollution from leaded gasoline) should be addressed [UN, 1994[132]].

[125] "[H]eavy metal problems in New Zealand, other than those related to lead poisoning, are more likely to threaten ecosystems than human health". (p. 6)

[126] "The Toronto SCOPE Workshop considered various aspects of the occurrence, flux, compartmentation and residence times of four elements which have been recognized as significant environmental pollutants over the past two decades. These are arsenic, cadmium, lead and mercury. Major gaps in our understanding of the global and regional fluxes for all four elements were identified, with data from developing countries in general being especially scarce." (p. xix)

[127] Partnership for Clean Fuels and Vehicles (PCFV).

[128] Global Alliance to Eliminate Lead Paint (LPA): its membership includes some government agencies and non-governmental (primarily business) organizations.

[129] Ban Mercury Working Group (BMWG, 2002-); Zero Mercury Working Group (ZMWG, 2005-).

[130] Global Mercury Partnership (GMP).

[131] ICMM, 2009: Mercury risk management: position statement. International Council on Mining and Metals.

[132] "169. The Commission recognizes the importance of taking action to address the health and environmental impacts of chemicals. It notes, for example, the severe health impacts of human exposure to lead, endorses the ongoing work on that issue in several international forums and encourages further efforts to reduce human exposure to lead."

Despite the worrying results of extensive scientific studies, no consensus emerged about the need for a global policy and/or legal instrument for addressing lead, and similarly, at least until 2007, no such deal was achieved for mercury. Therefore, during that period, UNEP and WHO could only facilitate international cooperation on voluntary commitments by the relevant stakeholders in this context.

1.3. GLOBAL 'DETOXIFICATION': PROGRAMS AND AGREEMENTS

1.3.1. International policy cooperation and instruments

International programs on hazardous chemicals have been elaborated and adopted that consist of environmental and health protection goals, policies, and measures. Such provisions have been based on the rapidly growing body of observational information and scientific findings, besides taking into account the multifaceted social, economic and technological aspects of implementation.

- The International Programme on Chemical Safety (IPCS) was proposed in the late 1970s by the WHO and commenced in 1980 as a joint initiative of the WHO, UNEP, and ILO: "The Health Assembly in May debated the health effects of chemical substances in the environment and requested that international cooperation should be promoted in the evaluation of the health effects of toxic and hazardous chemicals. Subsequently, the first steps were taken to establish an international programme on chemical safety …" [WHO, 1979: par. 153]. This program fostered the definition of policies and measures for the prevention or at least reduction of chemicals-related hazards by supporting the relevant research activities, and in this regard, special attention was first paid to toxic heavy metals in the framework of European-level cooperation [WHO, 1992].[133] The global environmental dimension of chemical safety was closely linked to other themes of environmental security [Faragó, 1996].
- After the historic 1992 UN conference (UNCED), the role of the IPCS was taken over by two international institutions: the Intergovernmental Forum on Chemical Safety (IFCS, 1994-) and the Inter-Organizational Programme for the Sound Management of Chemicals (IOMC, 1995-). Besides the above-mentioned ones, other organizations were involved in this collaboration. (Later on, this enlarged and effectively functioning institutional network contributed greatly to (i) the genesis of the 2006 global chemical management strategy that included, inter alia, policy recommendations on toxic heavy metals and (ii) the successful negotiations of the global convention on mercury, adopted in 2013.[134])
- Some specialized organizations of the UN have also acted independently in accordance with their own mandate. For example, in 1994, UNIDO launched its own Global Mercury Programme with the aim of minimizing the use of mercury in industrial processes and the resulting environmental pollution [UNIDO, 2013].
- The UNEP coordinated the implementation of an action plan from 1995 on with the general objective of protecting the marine environment from land-based activities (GPA-LbA),[135] one important element of which was the prevention/elimination or at least reduction of heavy metal pollution (in particular, the emission of mercury pollutants).

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[133] "2. One of the specific purposes of IPCS is to assess the risks to human health and the environment posed by chemicals, whatever their origin or wherever they are found, thus providing internationally evaluated scientific information on which Member States can base their chemical safety measures." "39. Since 1986, the Regional Office for Europe has launched several technical projects including: […] (2) collaborative epidemiological studies and research projects on lead, cadmium, formaldehyde, methylmercury and dioxins".

[134] György Ungváry played a key role in these endeavors as vice-president of IFCS; moreover, in the preparation of a publication summarizing this subject area that covered tasks in connection with heavy metals, too [Ungváry, 2006].

[135] *G*lobal *P*rogramme of *A*ction for the Protection of the Marine Environment from *L*and-*b*ased *A*ctivities (GPA-LbA)

- In the absence of global approval, at least a regional consensus was achieved about the hazards associated with a widely used lead compound and the need to gradually eliminate its application, leading to the acceptance of the *Pan-European Strategy to Phase Out Leaded Petrol* in 1998.
- Sharp debates and conflicts of interest regarding the utilizations and harms of lead and cadmium have prevented a consensus emerging about the necessity of a global program for addressing the broad spectrum of issues concerning all these three toxic heavy metals, and that perhaps could even lead to a comprehensive regulation.[136] Therefore, a decision could only be made on the UNEP's Global Mercury Programme in 2003 on the basis of the first *Global Mercury Assessment* [UNEP/GMA, 2002].

1.3.2. The global strategy and action plan

Despite decades of proliferating observations and studies on chemicals that show they pose risks to health and the environment, it proved impossible to define any more or less concrete goals and determine actions at the global level, including provisions concerning toxic heavy metals among the chemicals of particular concern. In this regard, the turning point was brought about by the 2002 World Summit on Sustainable Development.

Sustainable development and chemicals management. The outcome document of the 2002 summit called for achieving by 2020 the sound management of chemicals and hazardous wastes, in particular, minimizing the serious health and environmental effects [UN, 2002: par. 23]. The greatest attention was paid to mercury-related problems and the measures necessary for their management [UNEP, 2002].[137]

- In order to meet this objective, it was stipulated that an international strategy for chemicals management would be prepared by 2005, which should include, among other things, the promotion of risk reduction related to heavy metals harmful to human health and the environment. It was also planned to have the Globally Harmonized System for the classification and labeling of chemicals (GHS) fully operational by 2008.
- Thus, a high-level decision was made that referred to the precautionary principle. Actually, the application of such a 'cautious' approach would not have been justified since, in the case of quite a lot of chemicals, their significant adverse effects had already been sufficiently proven. (It should also be noted that the 'definition' of the precautionary principle as formulated in 1992 included the rather ambiguous 'cost-effectiveness' criterion.)

Sound management of chemicals and toxic heavy metals. The elaboration of that global strategy started in 2003, and eventually, a document entitled *Strategic Approach to International Chemicals Management* (SAICM) was adopted in 2006 at the first session of the International Conference of Chemicals Management (ICCM). It included an *Overarching Policy Strategy* and a *Global Action*

[136] The author of this book had the opportunity to participate in the 2003 session of the UNEP Governing Council (UNEP-GC). During the debate, some delegations vehemently opposed the extension of a possible global program to lead and cadmium, while others argued that it should not be limited to mercury. Among the opponents, quite a few developed and developing countries were widely known for their significant extraction and exploitation of and commercial interests in these two toxic heavy metals (i.e., Pb and Cd).

[137] "22. Measures to reduce and/or eliminate mercury in wastes through mercury waste management might include: (a) Limiting or preventing mercury in products and process waste from being released directly into the environment, by efficient waste collection; […] (c) Limiting or preventing mercury releases into the environment through treatment of household waste, hazardous waste and medical waste, by emission control technology; […] (g) Preventing mercury releases into the environment through the management of obsolete and waste pesticides and chemicals containing mercury; […] (i) Limiting or preventing the incineration of mercury containing products, materials and waste".

Plan. Multilateral environmental diplomacy played a major role in shaping the SAICM, that is, via proposing reasonable compromises that fostered reaching a consensus.[138]

- The general objective of the strategy was literally in line with what was contained in the above-mentioned WSSD document, with a 2020 target date for the sound production and use of chemicals. This comprehensive strategy touched on toxic heavy metals, as well: "57. Promote reduction of the risks posed to human health and the environment, especially by lead, mercury and cadmium, by sound environmental management" [SAICM, 2006].
- The *Global Action Plan* set out more concrete measures, in particular, for these substances: "8.d. Promoting the reduction of risks from mercury and other chemicals of global concern so that they are minimized", "49. Eliminate lead in gasoline", "60. Consider the review of scientific information, focusing especially on long-range environmental transport […] on the need for global action in relation to lead and cadmium". The proposed actions for hazardous wastes were also applicable to these chemicals. Moreover, the plan reiterated a much more stringent solution, at least for mercury, that had already been discussed for some time within UNEP: "58. Consider the need for further action on mercury, […] including the possibility of a legally binding instrument".

1.3.3. International environmental agreements covering, inter alia, toxic heavy metals

Since the 1970s, international legislation has been prepared that regulates the use of chemicals and hazardous wastes and control the related pollution. These regulations also aim to reduce emissions and the harms caused by mercury, lead, cadmium, and their compounds.

Marine pollution. Global legal instruments intended to control, but above all to avoid or, ab ovo, prevent marine pollution induced by hazardous substances (whether intentional or unintentional) have become more complex and stringent since the 1970s.

- One way to 'get rid' of heavy metal waste is to dump it in the open sea, a practice that the international community has taken legal action against but which is difficult to prove. The 1972 *London Convention* at last expressly banned such dumping of waste containing, for instance, mercury, cadmium, or their toxic compounds and imposed less rigorous rules on lead-containing waste [LC, 1972].[139]
- The carriage by sea of lead, mercury, and their compounds, among many other dangerous substances, was prohibited by international agreements aimed at preventing pollution from ships [MARPOL, 1973; MARPOL/MP, 1978][140].

International 'waste trade'. The difficult problem of the disposal of hazardous waste has been 'solved' cost-effectively by exporting it to another country instead of treating it in the country of its

[138] The Preparatory Committee (PrepCom) for the strategy was chaired by Viveka Bohn from Sweden, who managed to propose reasonable compromises (solutions and formulations) tentatively acceptable to all participating delegations. The author of this book had the opportunity to participate as a Hungarian delegate in the 2006 event at which this strategy was finalized and adopted. Consensus could be reached on some critical points through 'last minute' compromises – for instance, on the precautionary approach by emphasizing risk minimization and by clarifying that this strategy is not a legally binding instrument but only includes tasks that can be undertaken and completed voluntarily.

[139] Article IV.1 "(a) the dumping of wastes or other matter listed in Annex I is prohibited"; Annex I: „2. Mercury and mercury compounds. 3. Cadmium and cadmium compounds." Article VI.1 "Each Contracting Party shall designate an appropriate authority or authorities to: (a) issue special permits which shall be required prior to, and for, the dumping of matter listed in Annex II"; Annex II: "Wastes containing significant amounts of […] lead […] and compounds".

[140] This international legal instrument (MARPOL Annex III) prohibits, with some exceptions, the carriage by sea of dangerous substances that are included on a special list. The latter is updated and supplemented from time to time by the International Maritime Organisation (IMO: *International Maritime Dangerous Goods Code*).

origin and according to the respective country's regulations. Taking into account the situation and interests of the countries that receive such shipments, the following international instruments have been developed.

- The *Basel Convention* of 1989 strictly controls international trade in hazardous waste and itemizes the waste types containing mercury, lead, or cadmium that fall under the scope of this agreement [BC, 1989].[141] Although the *Cairo Guidelines* for the environmentally sound management of hazardous waste introduced in 1987 were applicable to such international shipments, they have not been sufficiently effective at preventing related incidents – for example, those involving waste containing toxic substances being taken from a developed country to a developing country for 'recycling' that caused severe health and environmental problems. This recognition led to the development of the above-cited convention, with the aim of preventing damages in the potential destination countries for receiving hazardous waste. In 1995, the convention was supplemented with the strict provision that in the future, developed countries should not export hazardous waste at all (that is, for any purpose).[142]
- The *Rotterdam Convention* adopted in 1998 on the international trade of hazardous chemicals and pesticides determined the rules for the prior informed consent procedure that (potential) exporting and importing parties must comply with [RC, 1998]. Recommendations for such a procedure were already provided in 1978 by the *London Guidelines*,[143] which were stipulated as legal obligations by the above convention. The latter's scope covers chemicals in which trade is banned or severely restricted, and their annexed list includes certain mercury and lead compounds. This convention does not contain specific provisions on hazardous wastes, but concerning their regulation, it refers to the *Basel Convention*. Consequently, these two global conventions are complementary in their approach to international trade in hazardous substances, including toxic heavy metals and their compounds.

International transport of these toxic substances. The global and regional regulations for international carriage of dangerous goods also apply to shipments containing toxic heavy metals. These instruments are designed to define the basic safety conditions/obligations for such transports and to minimize the harmful effects in the event of an accident.

- Two early cases may be mentioned. In February 1944, a cargo ship bound for New York from a Canadian seaport ran aground and sank, along with the large quantities of mercury it was carrying [NOAA, 2013].[144] The spill of this toxic metal has also led to aviation incidents, such as one involving a TWA flight in January 1971, which affair was the subject of a US congressional investigation [US-Congress, 1974].[145]
- The first global-level recommendations for the transport of dangerous goods (including those containing lead, mercury, or their toxic compounds) were adopted many decades ago [UN, 1956].

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[141] "1.1. The following wastes that are subject to transboundary movement shall be 'hazardous wastes' for the purposes of this Convention: (a) Wastes that belong to any category contained in Annex I"; Annex I: "Y29 Mercury; mercury compounds […] Y31 Lead; lead compounds: 1.1.(a) To facilitate the application of this Convention […] wastes listed in Annex VIII are characterized as hazardous"; Annex VIII: "A1010 Metal wastes and waste consisting of alloys […] Cadmium Lead Mercury", "A1030 Wastes having as constituents or contaminants […] Mercury, mercury compounds".

[142] The *Basel Ban* would apply to the following developed countries: OECD members, EU Member States, and Liechtenstein; however, not all of them have undertaken this obligation.

[143] *London Guidelines for the Exchange of Information on Chemicals in International Trade* (1978).

[144] "In February 1944 the M/V Empire Knight, a 428-foot British freighter ran aground on Boon Island Ledge, Maine and later broke into two sections. The stern section which included the ship's cargo holds sank in approximately 260 feet of water, one and one half miles from Boon Island Ledge. […] Due to the presence of large amounts of hazardous mercury cargo, the U.S. Coast Guard has declared a Permanent Safety Zone around this wreck site." (pp. 4-5)

[145] FAA *Regulation Concerning Hazardous Air Cargo*. Hearings before the Special Subcommittee on Investigations "Eastern, Northwest and Delta have all experienced spills involving metallic mercury, which seriously damaged several aircraft. In January of this year a TWA passenger flight had to return to the airport after take-off because of a spill involving mercury." (p. 531)

The regulations for the air transport of such goods were developed by the International Air Transport Association (IATA) from 1953 on and have been recurrently supplemented and refined since then in cooperation with the International Civil Aviation Organization (ICAO) [IATA/DGR, 2022].[146] The maritime transport of these goods, including toxic heavy metal cargoes, is subject to rules set by the International Maritime Organization since 1965 [IMO/IMDGC, 2020].[147]

- Earlier maritime legislations were also taken into account in the development of the European Agreement on International Carriage of Dangerous Goods by Road (1957) and the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (2000) under the auspices of the UNECE. The latest versions of these instruments list all goods containing mercury, cadmium, or lead that are not allowed or are subject to specific conditions for international transport [ADN, 2021[148]; ADR, 2020]. The first legal instrument on international rail transport (1980) was regularly updated and extended (under the aegis of the international organization established for the cooperation on this matter), and its most recent version deals with the rules of carriage of dangerous goods by rail and lists in detail those toxic heavy metals and their compounds for which strict rules must be adhered to [OTIF/RID, 2021].

The environmental release and transboundary effects of toxic heavy metal pollutants. These pollutants can also be released into the environment as an inadvertent consequence of industrial and other human activities, occasionally leading to international problems. We have already discussed the long-range propagation of these pollutants and the scientific cooperation on this subject. Therefore, we only recall the relevant agreements below.

- The *Protocol on Heavy Metals* to the 1979 UNECE *Convention on Long-range Transboundary Air Pollution* was adopted in 1998 as one of the major outcomes of the pan-European environmental cooperation that started in the early 1990s [CLRTAP/HM, 1998].[149] In accordance with that legal instrument, the systematic emission reduction of cadmium, lead, and mercury pollutants began, resulting in the lessening of their long-range transmission and harmful effects. Such obligations have gradually become stricter, including lower emission limit values and promoting the use of the best available techniques for various sources of this pollution; moreover, increasingly stronger product control measures, such as the phase-out of mercury-containing batteries and lead additives in gasoline. (It is worth noting that the *Convention on the Transboundary Effects of Industrial Accidents* [CTEIA, 1992] refers in general to the risks of accidents accompanied by the environmental release of toxic substances, but in this regard, only lead compounds used as anti-knock additives in gasoline are specifically mentioned on the list of such substances.)
- Two major conventions have been concluded to protect international watercourses from pollution. The scope of the 1992 UNECE *Convention on the Protection and Use of Transboundary Watercourses and International Lakes* was extended to a global level in 2003, thus allowing States outside the pan-European region to become Parties to this legal instrument (from 2013 on, when this amendment entered into force). The hazardous substances defined in that convention include toxic heavy metals, and the obligations of Riparian Countries first of all mean the introduction and implementation of measures to prevent, control, and reduce the release of such substances into the aquatic environment [CTWC, 1992]. This regulatory instrument is actually a multilateral framework-type convention that encourages Riparian States of various international watercourses to conclude 'their own' agreements for harmonizing and strengthening collaboration based on the

[146] In air transport (cargo), too, the carriage of certain dangerous goods and substances containing mercury, cadmium, or lead is subject to a weight limit or is completely prohibited, while for passenger transport, even stricter rules apply.
[147] Class 6.1: Toxic substances; Class 9: Miscellaneous dangerous and environmentally hazardous substances.
[148] Such rules concerned, for instance, mercury-based pesticides.
[149] The goal for all three heavy metals was to bring countries' emissions to below 1990 levels (a different reference year could be specified under certain conditions). The annexes to the Protocol listed non-binding requirements to be applied within a specified timeframe for industrial activities (e.g., metallurgy), other emission sources (e.g., waste incineration) and products containing these chemicals (e.g., mercury oxide batteries).

principles and common provisions of this UNECE document. (One such example is the *Danube River Protection Convention*, which explicitly lists mercury, cadmium, and lead among the hazardous substances [DRPC, 1994][150].) The 1997 global *Convention on the Law of the Non-Navigational Uses of International Watercourses* similarly provided a general legal framework for agreements to be concluded by States in whose territory part of an international watercourse is situated and which decide on the concrete ways and means of their collaboration, including the measures for preventing the water pollution by hazardous substances [UNWC, 1997].[151]

Lead was used in hunting and fishing equipment for a long time, but without recognizing the injurious influences of the toxic heavy metal particles that were sometimes unintentionally left behind in the natural environment or whose hazards were simply considered negligible.

- The *Agreement on the Conservation of African-Eurasian Migratory Waterbirds* requires its States Parties to strive to eliminate hunting with lead shot in wetlands and fishing with lead weights, "noting that lead in general poses a threat to the environment with harmful effects on waterbirds" [AEWA, 1995: par. 4.3.12]. In 1999, the Parties decided that the use of lead shot in hunting in such areas should be completely eliminated by the year 2000.
- The provisions of the *Convention on the Conservation of Migratory Species of Wild Animals* are also essential in this context [CMS, 1979]. More specifically, in 2014, the Parties to the Convention adopted guidelines on controlling the use of lead in hunting and fishing.[152] In 2019, a special working group was established with the mandate to consider options for more effective regulatory means for the prevention/reduction of such lead poisoning.

The European Union has taken a strong stance on restricting the use of hazardous chemicals in the course of the elaboration/negotiation of the global chemicals strategy (SAICM), the convention on mercury (MCM), and other agreements mentioned above. In addition, these goals and the relevant rules were consistently reflected within 'internal' EU legislation (Acquis Communautaire), thereby also contributing to the achievement of the objectives adopted by the international community.

- The European Union, as a 'regional economic integration organization' has itself become a Party (besides its Member States) to most of the aforementioned agreements. The EU's relevant, comprehensive legal act, that is, the *Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals*, was adopted a few months after the adoption of the global chemicals strategy [EU/REACH, 2006]. Some years later, a directive was approved restricting the use of certain hazardous substances in electrical and electronic equipment [EU/RoHS, 2011]. Also in 2006, the legal instrument on batteries and accumulators was published, followed by its much more stringent version in 2013 [EU/Batteries, 2006, 2013]. The recommendations and/or regulations introduced by developed countries' organizations (primarily by EU and OECD) have contributed to the global reduction of the harmful effects of these substances through international economic, trade, technical, and development cooperation [OECD, 2017].
- The abovementioned EU legal acts regulate in detail the production, placing on the market, trade, and management of e-waste of products containing mercury, lead, cadmium, and some of their compounds in order to protect health and the environment. In addition, a 2008 regulation specifically addressed mercury, which was renewed in 2017, taking into account the goals and provisions of the global *Minamata Convention on Mercury* (MCM). This latest EU act made it clear that the EU would thereby contribute to achieving the objective of the Convention, and also

[150] Annex II, Part 2: Guiding list of hazardous substances and groups of substances.
[151] Article 21: "3. Watercourse States shall […] (c) Establishing lists of substances the introduction of which into the waters of an international watercourse is to be prohibited, limited, investigated or monitored."
[152] *Preventing poisoning of migratory birds*, UNEP/CMS/Resolution 11.15 (2014)

that a comprehensive solution to the mercury-related problematic would only be possible through effective global cooperation [EU/Mercury, 2017].[153]

1.3.4. Global convention on mercury (without addressing lead and cadmium)

The international debate intensified after the 2002 WSSD concerning whether there is a need for global regulation about toxic heavy metals.

- As mentioned above, in 2003, it was only possible to reach a consensus on the *Global Mercury Programme* (GMP), even though many governmental and non-governmental representatives argued that this program should have been extended to lead and cadmium; moreover, instead, a legally binding instrument, at least for mercury, would have been more necessary. Along with many developing countries, even the USA was against such a convention at that time. (In contrast, the USA later not only supported it but became the first Party to it, submitting the 'instrument of acceptance' one month after the convention was adopted on 10 October 2013.) In comparison, all EU Member States and the majority of associated countries (including Hungary) have taken the position since the late 1990s that a global agreement covering all three toxic heavy metals needs to be developed.[154] The group of northern European states specifically emphasized the importance of limiting cadmium use and emissions: "The environmental fate and the toxicity of cadmium calls for a global initiative aimed at minimising human and environmental consequences of the ongoing cadmium emissions. […] Global efforts addressing cadmium may include a phase-out of cadmium in products as well as global agreements of improved emission control related to air as well as water emissions." [NCM, 2003: p. 4]
- Non-governmental environmental organizations have argued most vehemently for the global regulation about toxic heavy metals and especially for the elimination of all uses of mercury as soon as possible. "The tripling in mercury levels in the global environment for the past 100 hundred years has resulted in increased risks to all peoples, wildlife and ecosystems […]. Clearly, to avert a global mercury catastrophe, concrete and binding international action must be developed […] in order to protect children and future generations from mercury exposure – the world's toxic time bomb." [BMWG, 2003: p. 4]
- A few months after the endorsement of the global strategy on chemicals in 2006, one of the outcomes of an international meeting was the *Budapest Declaration on Mercury, Lead and Cadmium*. The participants invited the Governing Council of UNEP "to give high priority to considering further measures to address risks to human health and the environment from mercury and measures, as appropriate, on lead and cadmium, by assessing the need for further action […], including the possibility of establishing a legally binding instrument" and "to consider establishing a global mercury use and/ or release reduction goal" [IFCS, 2006: pars 6., 7.].[155] This clearly demonstrated that although the 'soft' provisions and voluntary actions recommended so far were relevant, they would not be sufficient in themselves without legally binding international

[153] (1): "Due to the transboundary nature of mercury pollution, between 40 % and 80 % of total mercury deposition in the Union originates from outside the Union. Action is therefore warranted at local, regional, national and international levels." (9): "This Regulation should complement the Union acquis and lay down the provisions that are needed to ensure the complete alignment of the Union acquis with the Convention so that the Union and its Member States are able to respectively approve or ratify and implement the Convention."

[154] The position of these European countries was largely supported based on the fact that the UNECE protocol on heavy metals was adopted in 1998 and entered into force in 2003.

[155] That statement specifically called attention to the importance of introducing of measures such as the "environmentally sound use, storage, recycling and disposal of mercury, lead and cadmium" and "export prohibition preventing excess mercury from re-entering the global market and a global phase out of primary production of mercury". The author of this book also participated in this conference as a member of the Hungarian delegation.

commitments to achieve the urgent minimization of the use of these substances and the harms they cause.

- As an international panel of experts was already dealing with a global assessment only on mercury,[156] a separate working group on lead and cadmium was convened and began its work in 2006.[157] This latter body was tasked with reviewing and summarizing the results of recent scientific research on these two toxic metals.
- The push for global regulation, at least for mercury, was again strengthened not only on the occasion of the adoption of the international chemicals strategy (2006) but also when the revised and extended mercury program of UNEP was approved (2007) and the second global report on mercury was published [UNEP/GMA, 2008].
- At the 2008 meeting of the Intergovernmental Forum on Chemical Safety (IFCS), attempts were again made to reach a consensus on the hazards of and coordinated actions required to deal with lead and cadmium, but only rather general recommendations could be agreed upon [IFCS, 2008].[158]
- In the context of the global environmental observation system (GEOSS, established in 2005), it emerged in 2009 that more attention should be paid to mercury-related (transmission and concentration) measurements and analyses than before.[159]

A decision was finally made in 2009 to start working on a global agreement. However, the preparations took a long time due to the very different situations and interests of the countries involved. Eventually, these negotiations were finalized in 2013 with the adoption of the *Minamata Convention on Mercury*.

- The debate held by the Governing Council of the UNEP in 2009 again featured long-standing arguments and counterarguments. Some delegations opposed any regulation on lead and cadmium (e.g., citing some controversial research findings and wide-ranging economic interests), while others argued that restrictions on the use of these two heavy metals were urgent. Also, due to differing perceptions of the severity of the harms posed by mercury, there were conflicting views on whether voluntary or mandatory measures were needed. Some considered it still scientifically insufficiently well-founded and, therefore, premature to adopt binding obligations on mercury, while others considered it very timely.[160]

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[156] UNEP: Global Mercury Assessment Working Group.

[157] UNEP: Working Group on Lead and Cadmium.

[158] "The need for efforts by Governments and other relevant stakeholders to reduce risks to human health and the environment of lead and cadmium throughout the life cycle of those substances […] to consider measures at the national, regional and global level to promote the substitution of lead and cadmium containing products by safe and feasible alternatives". (p. 15)

[159] To this end, an EU-funded Global Mercury Observing System (GMOS) was set up in 2010, and later, its role was taken over by the Global Observing System for Mercury (GOS4M) as part of GEOSS. Furthermore, based on the increasing volume of such observational data and assessments, a "knowledge hub" was planned from 2017 that became operational in 2020 and proved to be useful for monitoring the implementation of the mercury convention: "Decision-makers require information on changes of Hg levels in the environment, in biota, and vulnerable populations, so that they can be attributed to the implementation of the Convention. They also require an assessment of the actions taken in terms of the changes in Hg supply and usage, and the resulting variation in Hg emission and release to the environment." [Simone et al., 2021: p. 235]

[160] The author of this book also took part in this meeting, where there was a lively debate on the content of a possible global convention, some aspects of which are worthy of special mention: (i) a significant turnabout was the US supporting the EU position that the mercury convention was necessary; (ii) India and China would have considered only voluntary measures to be appropriate (this problem was later overcome by the more 'open' wording of certain provisions); (iii) global regulations on lead and cadmium were considered unacceptable by, e.g., Australia, Japan, China, South Korea and the USA (obviously, because of their economic interests). Compared to the very different positions on many issues, it was almost a 'miracle' that the convention was compiled and adopted within four years.

- Ultimately, a decision was made after accepting serious compromises, and the resulting convention adopted in 2013 only dealt with mercury and included numerous exceptions and temporary exemptions, furthermore leaving the restriction of certain applications to the 'voluntary' decisions of the respective countries [MCM, 2013].

Compromises, exceptions, exemptions. Key components and compromises of the mercury convention are presented below that also reflect the extent to which 'harmony' (consensus) could be achieved between the negotiating parties with very different positions and how the major conflicts of interest were somehow resolved. (The history and provisions of this convention were reviewed and evaluated in detail shortly after its adoption [Faragó, 2015].)

- The most essential exceptions for which no specific goals (target dates and limit values) could be agreed upon but only that all Parties would consider a gradual reduction in the use of mercury in such applications are as follows: (i) a chemical used to preserve vaccines (thiomersal); (ii) dental amalgam; and (iii) artisanal and small-scale gold mining (ASGM). The socioeconomic background of the latter was well known, namely that this activity still provided a livelihood for millions of people around the world.
- As to the mercury-containing waste, this convention 'relied' on the 1989 *Basel Convention* on hazardous wastes and their transboundary movements (in this sense, these two legal instruments complemented each other) [MCM, 2013].[161]
- Specific targets and temporary exemptions include (i) the manufacture and international trade of mercury-containing products to be terminated by 2020 (e.g., most of such batteries and fluorescent lamps, thermometers, barometers, pesticides); (ii) the industrial processes using mercury (e.g., the use of mercury must be halved compared to its 2010 levels in the production of Vinyl Chloride Monomer /VCM/, a compound for producing PVC); (iii) ceasing (primary) mercury mining in a State's territory within a decade and a half after the Convention enters into force for the former; and (iv) setting specific targets for reducing atmospheric mercury emissions from existing sources (e.g., coal-fired power plants) within ten years of the entry into force of the Convention. Exemptions from these obligations can be requested for a period of five years, which can be extended once.
- The *Minamata Convention* entered into force in 2017, but a number of States are still not Parties to it (about one-fifth of the UN Member States). Therefore, for this reason, and due to the above-mentioned exceptions and exemptions, mercury use and mining may stay with us for a long time to come.

1.3.5. Global 'non-regulation' on lead and cadmium

No consensus has been reached on global regulations concerning lead, cadmium, and their hazardous compounds due to differing views on their utilization and harmful effects.

- No reference to the two other toxic heavy metals, viz., lead and cadmium, could be included in the text of the 2013 *Minamata Convention on Mercury*, and not even a suggestion indicating the possibility of the future extension of its scope. During the debate about the mandate of the International Negotiating Committee (INC) established in 2009 to draft the convention, it was suggested that this mandate could be expanded to include the consideration of regulatory options for lead and cadmium at a later date. At that time, although this possibility was included in the relevant UNEP decision, due to the lack of consensus, the text did not even mention the 2006

[161] Article 11 Mercury wastes: "3. Each Party shall take appropriate measures so that mercury waste is: (a) Managed in an environmentally sound manner, taking into account the guidelines developed under the Basel Convention […]; (b) Only recovered, recycled, reclaimed or directly re-used for a use allowed to a Party under this Convention or for environmentally sound disposal".

Budapest Declaration on all three toxic heavy metals [IFCS, 2006]. Obviously, for the same reasons, any reference to lead and cadmium, their applications, and harms was completely omitted from the new global chemicals framework [IOMC, 2023].[162]

- Instead of advocating for and promoting the development of global obligations on the two other toxic heavy metals, one option left for UNEP and WHO (together with some other organizations such as FAO, WTO, and EU) was to support the activities of international networks/partnerships opposing at least the use of leaded gasoline, lead-containing paints and fostering the avoidance/minimization of food contamination by these toxic heavy metals and compounds [UNEP-PCFV, 2017; UNEP-LPA, 2019; WHO, 2020; FAO/WHO, 2019; WTO/EU-ICCO, 2022]. They also assisted in the implementation of the global chemicals strategy, which covered lead and cadmium as well.

* * *

Following the discovery of the serious health and environmental harms caused by toxic heavy metals and the formulation of recommendations by international expert bodies based on the increasing evidence of this hazardous problem derived from observations and research results, international policy and regulatory instruments have been developed to limit or phase out numerous uses of these substances. Thanks to the implementation of these programs and agreements to date, the environmental releases of these toxic chemicals have considerably decreased. However, still in a number of applications, due to various factors, it has not been possible to agree on the need to eliminate the use of these substances worldwide within a relatively short period of time. In this regard, conflicts of interest (related to socioeconomic, trade, technological, or other factors) remain for a number of countries and companies, particularly in the case of lead and cadmium. Nevertheless, at least in terms of mercury, the global agreement reached in 2013 is promising despite the large number of compromises contained therein and the rather long deadlines for the universal implementation of some of its obligations.

1.4. WILL WE FINALLY ELIMINATE THE USE OF TOXIC HEAVY METALS?

It is an outstanding achievement in terms of international environmental cooperation that policy programs and agreements have been formulated to control human activities responsible for the serious harms caused by toxic heavy metals based on extensive observations and the increasingly evident results of scientific research. However, the adequacy of such policy or legal instruments for achieving the ultimate objective of the significant reduction or even complete cessation of these harms can only be judged on the basis of the provisions contained therein, such as the specific goals, actions, means of implementation, their exact phrasings reflecting compromises, the possibilities for exceptions, and binding or voluntary requirements/commitments, etc. This approach is commonly referred to as the evaluation of the *environmental or ecological effectiveness* of the pertinent instruments. In other words, this also means the matching of the set of concrete goals, policies, and measures contained in the document approved by consensus with the scientific knowledge revealed about the extent and severity of the adverse implications, their causal relations, and the science-based recommendations for the necessary interventions. The *institutional and legal effectiveness* of such international programs/agreements, based on the assessment of their (f)actual realization, can be assessed (only) in comparison to the former: i.e., of their provisions, what was de facto fulfilled (first of all, the approved requirements/commitments) and the knowledge of whether their specific goals were fully or at least partially achieved. We will begin by addressing these latter aspects of effectiveness (1.4.1., 1.4.2.).

[162] The new framework strategy on chemicals was adopted in 2023, 'replacing' SAICM (which was designed for the 2006-2020 period).

1.4.1. Differentiation in obligations and means of implementation

The institutional/legal effectiveness of the international environmental programs and agreements discussed in this chapter related to the use of and hazards caused by toxic heavy metals depend on (i) the extent to which their provisions reflect the differences in responsibilities of the countries (respective groups of countries) concerning the emergence and escalation of these hazards, (ii) their different situations regarding the utilization and environmental releases of these substances and the resulting adverse effects, moreover, (iii) their commitment and ability to phase out the manufacturing of products containing and technologies using such chemicals.

The significance of such multilateral policy or legal instruments may be assessed primarily by how 'universal' they have become – that is, how complete or incomplete the list of countries of which relevant representatives have declared a readiness to take part in their implementation. As to legally binding agreements, of course, this refers to the completeness or incompleteness of the range of those States which became Parties to them.

- The 2006 global chemical strategy (SAICM) – in line with the relevant chapters of the 2002 sustainable development plan – contained an ambitious, broadly defined goal for the sound management of chemicals with a target date of 2020. This was also applicable to lead, mercury, and cadmium, with the general aim of eliminating or at least substantially reducing their health and environmental impacts. Moreover, some specific targets for them were determined in the strategy's action plan.

- The greatest merit of this strategy was its comprehensive or framework nature, that is, the fact that it addressed all essential components and areas of this broad problematic and referred to all 'actors', including international organizations and non-governmental stakeholders, in addition to national governments [NCM, 2017]. However, regarding its institutional/legal effectiveness, it is first advisable to clarify how many of the latter (in what way and to what extent) they have identified with the goals and tasks listed in the strategy and its action plan. This would be demonstrated, for example, by the preparation of their national implementation plans and the indication in the progress reports of actions and accomplishments for properly controlling the use, inter alia, of toxic heavy metals and reducing their environmental releases and harms. According to the International Conference on Chemicals Management (ICCM) – the organization coordinating the execution of this strategy designed for the 2006-2020 period – just over a quarter of countries and only a few non-governmental and international organizations have published such information [ICCM, 2019].

- As mentioned, the conventions regulating the international trade in (or in a broader sense, the 'transboundary movement' of) hazardous chemicals and wastes also apply to toxic heavy metals. The *Basel Convention* has become almost universal, while many developing countries have not (yet) become Parties to the *Rotterdam Convention*. (It should be noted that the USA has signed both conventions but has not ratified either.) The 1995 *Ban Amendment to the Basel Convention* only entered into force at the end of 2019, as many countries considered at length whether to sacrifice their (economic, commercial, and other) interests to ensure compliance with these newer strict obligations. Let us remind the reader that in line with that amendment, it became completely prohibited for developed countries to export hazardous wastes as defined in the convention to other countries. Consequently, the former must ensure the minimization and disposal of such wastes (including those containing toxic heavy metals) 'at home', based on their own legislation. It may be indicative of the continuing practice of such international transactions that nearly half of the UN Member States did not become Parties to that amendment, including some developed countries (in addition to the USA, e.g., Australia, Canada, and Japan).

- The global *Minamata Convention on Mercury* and the UNECE *Protocol on Toxic Heavy Metals* allowed for numerous exceptions and temporary exemptions, but as to the effectiveness of these agreements, we start again by examining how complete or incomplete is the list of participating countries that have officially undertaken to deal with the implementation of these legal instruments. As a matter of fact, quite a few UN Member States have not yet become Parties to that convention (the potential reasons for this are mentioned by the author in a separate study [Faragó, 2018b]), and the situation is rather similar in terms of the pan-European protocol (of course, with regard to the countries belonging to this region). Let us add that according to the convention, information on progress in fulfilling the commitments should be published in national reports, but based on the latest information, many Parties have not met this obligation (which is also one of the obstacles to assessing the overall effectiveness of the Convention).
- Some of the above-mentioned programs were originally initiated with the involvement of governmental and non-governmental organizations with some particular goal in mind: for instance, the Global Alliance to Eliminate Lead Paint (LPA) aimed to have such national legislation in place in every country [UNEP-LPA, 2019]. However, this has only been achieved in about forty percent of countries.

Means of implementation. In addition to compromises on goals and obligations regarding the toxic heavy metals, the extent to which engagement in a program or agreement becomes widespread may also depend on the instruments supporting especially those developing countries that were in a complicated position with regard to these substances and/or the interventions that seemed necessary to resolve the ensuing problems. Above all, these means incorporate providing (i) preferential access to and transfer of environmentally friendly technologies for lessening/terminating the use of these toxic chemicals and their adverse influences and (ii) financial resources, i.e., financing projects for creating and implementing policies and measures for the above purposes in accordance with the relevant international program/agreement.[163]

- The Global Environment Facility (GEF) is one of the institutions that was established with this aim [Pató & Faragó, 2004].[164] Along with many other global environmental agreements, this has become the primary international financial mechanism that supports the execution of the *Minamata Convention* [MCM, 2013].[165]
- The importance of these means was emphasized in the 2006 chemicals strategy (SAICM), but their application has not been sufficient. This was a key factor in why the aforementioned 2019 report of the International Conference on Chemicals Management found that one of the main obstacles to achieving the common strategic goals was the lack of the necessary capacities in most developing countries. This was clearly valid for mercury-related commitments, and with this in mind, the decision-making bodies of the *Minamata Convention* and the Global Environment Facility agreed to strengthen their collaboration in 2019.[166] (Typical projects approved and funded by the GEF were those assisting the eligible countries

[163] The most essential elements of such 'means of implementation' are exemplarily listed in Agenda 21, beginning with the financial and technological components, viz., "33. Financial resources and mechanisms" and "34. Transfer of environmentally sound technology, cooperation and capacity-building". [UN, 1992]

[164] The CEE-countries 'in transition to a market economy' (including Hungary) were also eligible in the 1990s to submit projects to and receive financial assistance for their implementation from the Global Environment Facility in accordance, for instance, with international agreements on ozone layer depletion and climate change (which themes are discussed in further chapters of this book).

[165] Article 13. Financial resources and mechanism: "2. The overall effectiveness of implementation of this Convention by developing country Parties will be related to the effective implementation of this Article. […] 7. The Global Environment Facility Trust Fund shall provide new, predictable, adequate and timely financial resources to meet costs in support of implementation of this Convention as agreed by the Conference of the Parties."

[166] Memorandum of Understanding Between the Conference of the Parties to the Minamata Convention on Mercury and the Council of the Global Environment Facility. GEF/C.56/10/

in preparing and implementing national projects for controlling/reducing mercury applications, including artisanal and small-scale gold mining.[167])

1.4.2. Evaluation of the implementation of international programs and agreements

The next stage of the general evaluation of the effectiveness of a program/agreement created as the outcome of an intergovernmental negotiation process is based on those internationally coordinated and national-level policies and measures that have been defined and realized in order to meet the specific goals, fulfill the obligations and accomplish the tasks contained therein.

The global chemicals strategy was designed for the period to 2020 and also called for the cessation of the use of mercury, phasing out of leaded gasoline, and the proper management of waste containing toxic heavy metals [SAICM, 2006]. As the target date approached, a thorough implementation report and the new *Global Chemicals Outlook* were completed [Nurick, 2019; UNEP/GCO, 2019].

- According to the latter's findings: "[T]he sound management of chemicals and waste and minimizing adverse impacts will not be achieved by 2020. […] Despite the regulatory actions taken, the market for most heavy metals (e.g., lead and mercury) remains stable. […] Moreover, toxic chemicals such as mercury, lead, and other heavy metals are mined, incorporated into products, and disposed of as wastes in the environment, where exposures of people and biota may be high." [UNEP/GCO, 2019: pp. 13, 19, 21] The strategy finalized and adopted in 2006 specifically emphasized the need to consider drawing up an international legal instrument on mercury, as if anticipating that the provisions contained therein might be of limited effectiveness without clearer binding obligations.[168] This also played a role in the completion of the mercury convention by 2013. (A decade later, the new chemicals framework strategy was approved, but it did not specifically mention the toxic heavy metal problematic, apparently in light of the existence of the global legal instrument on mercury that was already in force at that time [UNEP/GFC, 2023] and the reality of the lack of consensus concerning the formulation of global policies on controlling/reducing the use of the two other toxic heavy metals.)
- The progress report on the status of implementation of the global sustainable development agenda and goals [UN, 2015] contains a similar assertion: that the 2020 target for the sound management of chemicals and waste will not be achieved, and therefore, a new and more effective and coherent program will be needed [UN/GSDR, 2019]. Furthermore, greater synergy is essential in the realization and renewal of the pertinent programs and agreements, as well as between the activities of international organizations (UNEP, FAO, ILO, WHO, etc.). Concerning the toxic heavy metals, these interlinkages should be better reflected in the course of the implementation of the *Minamata Convention on Mercury* and the relevant provisions of the aforementioned sustainable development agenda, and also in the context of

[167] We mention here only one typical project approved in 2020 and funded by GEF, namely the GEF/UNIDO Project 'Minamata initial assessment and national action plan on the artisanal and small-scale gold mining sector in Nicaragua': National capacity and capability have improved in terms of the prevention and management of mercury use through the preparation of a Minamata Convention Initial Assessment (MIA) and a National Action Plan (NAP) for the artisanal and small-scale gold mining (ASGM) sector.

[168] "58. Consider the need for further action on mercury, considering a full range of options, including the possibility of a legally binding instrument". [SAICM, 2006: p. 36]

sound chemicals management and the conservation of biodiversity, including their follow-up policy frameworks [UNEP, 2020a[169]; CBD/GBF, 2022; UNEP/GFC, 2023].

The pan-European agreement on heavy metals (1998) required all Parties to reduce their total atmospheric emissions of toxic heavy metals, but without defining any concrete, time-bound overall reduction targets. However, the annexes to this legal instrument at least listed mandatory quantified limit values to be met in many cases within a 5-10 year period for certain emission sources (existing and new stationary sources such as coal-fired power plants, the chlor-alkali production process, and waste incinerators), as well as for some products (e.g., dry batteries). The 2012 amendment set a deadline of 2020 for existing stationary sources to comply with the new, stricter emission limit values and for chlor-alkali plants to either convert to mercury-free technology or close by the end of 2020. But this amendment only entered into force on 8 February 2022, and even then only for about half of the countries of this region which accepted it.

- When assessing the emission reductions based on the provisions set out in this agreement, it is primarily the data provided by countries in their reports that can be relied on. According to these information sources, atmospheric emissions of toxic heavy metal pollutants, in general, show a downward trend (especially in the western area of this region). The above-mentioned EU regulation covering these toxic substances imposed on EU Member States played a substantial role in this improving regional situation. Nevertheless, "[d]espite the continuous decrease of emissions of these pollutants in the past decades, these substances still cause adverse effects on human health and ecosystems" [EMEP, 2019: p. 10].
- From the observations and studies, the potential for the long-range atmospheric transport of these pollutants was reinforced, and as for mercury (Hg^0), its transcontinental or even hemispheric scale transmission [e.g., CLRTAP, 2010].[170] Consequently, this UNECE agreement can be considered of global significance for two reasons. (i) On the one hand, some of these pollutants emitted from the countries of the region – albeit at a decreasing rate – may be transmitted in the atmosphere far beyond the borders of this region. Therefore, the implementation of this protocol also contributes to reducing the harms induced by these toxic substances in more distant areas (as regards mercury, even at the global level). (ii) On the other hand, the level of this pollution in the territory of pan-European countries is considerably affected by mercury pollutants arriving from 'outside' and, to a somewhat lesser extent, by the incoming lead and cadmium pollutant fluxes [UNEP, 2010; EMEP, 2018].[171] Thus, regarding mercury in particular, minimizing regional health and environmental harms cannot be achieved solely through emission reduction measures realized in the countries of this region.

The global Minamata Convention on Mercury, approved in 2013, included only a few concrete, time-bound goals but mentioned numerous exceptions. These should also be taken into consideration in the assessment of the global effectiveness of this legal instrument – that is, when we examine the pace and extent to which its implementation is leading to a decrease in the use of this toxic metal and its compounds and their impacts on human health and the environment.

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[169] Linkages and Opportunities to coordinate and cooperate: "Ensuring the sound management of chemicals and waste is essential for advancing sustainable development across its social, economic and environmental dimensions. Chemistry and the chemical industry have important roles to play in achieving the sound management of chemicals and waste within a sustainable development context." Biodiversity. Characterization and Linkages: "the land degradation linked to informal mining or poorly regulated ASGM operations, often using mercury and occurring in the protected areas, needs to be tackled in a collaborative spirit by chemical governance and biodiversity actors." (pp. 10, 23)

[170] Spatial and Temporal Variability in Inter-Continental Transport: "Given the above discussion, and knowledge of the main air mass transport pathways, it is clear that there is a high potential for emissions in Asia, North America and Europe, especially of Hg^0, to be transported globally, and similar conclusions are likely for the Southern Hemisphere although there is little data available to confirm this." (p. 9)

[171] A well-known external source is the mercury-based technology used in PVC production, which has been gradually phased out in this region, but still persists elsewhere (a typical example of what is hopefully only a temporary phenomenon that is usually referred to as 'technological lock-in') [Tremblay, 2016].

- We have highlighted above some of the specific goals of this convention to be met by the 2020 deadline, but the efforts made to attain them have not proven sufficient. It was known from the outset that solving the 'mercury problem' would be complex and difficult to tackle, which not only has profound social and political implications but is also linked to other environmental processes and several scientific disciplines and economic sectors [Chen, 2018[172]; Bank, 2020[173]].
- As the 2020 deadline approached, it was clear that the production and international trade of certain mercury-containing products specified in the convention would not cease everywhere, nor would the amount of mercury used in the production of vinyl chloride monomer (VCM)[174] be halved [UNEP/GCO, 2019; MCM/PR, 2021; MCM/PR, 2023[175]].

The use of lead in hunting and fishing. The two previously mentioned nature conservation agreements aimed to phase out the use of lead shot and lead weights, primarily in wetlands.

- In 1999, the Parties to the *Agreement on the Conservation of African-Eurasian Migratory Waterbirds* (AEWA) decided that this goal should be reached by 2000, and then – after this was not achieved – the strategic plan adopted ten years later stated that the ban on the use of the associated shotguns in these areas should be implemented by 2017. As a matter of fact, a few years before the new deadline, less than half of the Parties were known to have introduced such a national-level regulation or at least developed one [AEWA, 2015], even though there would not be technical obstacles to transitioning to lead-free practice (although this would of course entail some costs) [Thomas & Guitart, 2018]. So, in this case, too, considerations focusing on environmental protection and nature conservation (and also indirectly on the preservation of human health) clashed with economic interests and habits (adherence to conventional tools and solutions).
- A similar conflict was reflected in the debate between those for and against the proposed stricter regulation within the European Union. In view of the adverse health and environmental aspects, it was planned to generally prohibit hunting with lead shot and fishing with lead weights after 2020, which proposal was considered completely unfounded by the international and EU-level organizations of hunters (CIC[176], FACE[177]). (Despite this, the relevant EU regulation was finally passed, according to which the use of this form of ammunition for hunting in wetlands throughout the EU was banned from 2023.[178])
- The same debate arose about cadmium when the EU was preparing to tighten the use of this toxic substance in batteries, which was considered unjustified by the advocacy organization representing the companies dealing with the mining, industrial application, trade, and distribution of cadmium and products containing it (ICdA).[179]

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[172] "Alterations of mercury cycling, mercury methylation, bioaccumulation, and trophic transfer due to climate and land use changes remain critical uncertainties in the ability of the Minamata Convention to reduce mercury releases and exposure." (p. 9559)

[173] "The MCM exists at the science-policy interface that is inherently complex, because providing scientific advice to policymakers often occurs within an interdisciplinary framework that involves political and social spheres." (p. 2) "New ways of thinking about this important environmental contaminant will be required in order to address this issue more holistically within the framework of MCM especially considering the incredibly short time frame, of six years, for the initial effectiveness evaluation." (p. 5)

[174] Vinyl chloride monomer is used for manufacturing PVC.

[175] "National reports submitted under Article 21 of the Convention revealed that 33 out of 113 reporting Parties had not yet taken measures to implement the 2020 phase-out deadline for mercury-added products." (p. 7)

[176] International Council for Game and Wildlife Conservation (Conseil International de la Chasse).

[177] Federation of Associations for Hunting and Conservation of the EU (Fédération des Associations de Chasse et Conservation de la Faune Sauvage de l'UE) [FACE, 2020].

[178] Regulation (EU) 2021/57.

[179] International Cadmium Association.

Illegal and informal international trade. Despite the fact that the *Rotterdam Convention* and the *Basel Convention* regulated in detail the trade in hazardous substances and wastes, the illegal and informal 'transboundary movement' of these heavy metals remained significant.

- It is estimated that mercury used in gold mining accounts for about half of this trade in many developing countries, while this trade is also important for the chlor-alkali industry, although to a lesser extent [UNEP, 2020b[180]; IUCN-NL, 2020[181]]. The *Minamata Convention on Mercury* regulated international trade in this toxic substance [MCM, 2013: 3.6-3.8] and even allowed trade with non-Parties under special conditions. However, at present, it is impossible to judge the global situation concerning this matter (also including illegal and informal trading) based on the limited information available from the national reports [MCM, 2023a].[182]
- Regarding lead-based paints, above all, a global agreement on lead could promote the restriction or even elimination of the currently unregulated and active international trade in this toxic product. The efforts of a non-governmental organization (LPA) have at least promoted in a number of countries the control of the use and trade of such paints (first of all, paints with higher lead content) [UNEP, 2020b[183]; UNEP-LPA, 2020].

1.4.3. Actual trends in the use and environmental releases of these toxic substances

The environmental effectiveness of the aforementioned programs and agreements may be most accurately demonstrated by examining the actual trends related to mercury, lead, and cadmium, indicating the reduction in their mining, processing, and utilization, together with the decreasing environmental releases and injurious implications of these toxic substances. Based on existing international policies and their implementation to date, as well as the extraction, production, and consumption data currently available, it seems quite obvious that getting completely rid of these toxic substances on a global scale will not happen in the short term. Most of the obstacles to and lessons learned from the execution of the former chemicals strategy clearly apply to these heavy metals [Nurick, 2019].

Estimating the effectiveness of the multilateral collaboration in the above sense is not a simple task in the case of mercury, both due to data deficiencies and the numerous compromises that have been made in the course of the elaboration of the global legal instrument on this toxic substance. A further problem in this regard is that many countries have not submitted reports or have communicated only partial information about their activities and the fulfillment of internationally accepted tasks.

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[180] [The conclusion] "is that about half of all mercury used in ASGM is traded illegally, and that for many of the individual countries involved, the use of illegal mercury is nearly 100 per cent." (p. 48)

[181] "During the research period (2018-2020), various factors aggravated the understanding of mercury trade and its supply chain. […] First of all mercury is deeply embedded in the ASGM tradition. […] The mercury trade is a lucrative business and many actors profit from it. Networks of informal mercury are well established and often linked to the gold trade, operating in a counter direction." (pp. 39, 43)

[182] "14. In their first full national reports, an increasing number of parties, compared to the previous, short reporting cycle, submitted information on exports of mercury from their territories […]. However, this information provides an incomplete overview of global mercury trade flows." "18. Parties also submitted information on measures taken to prevent exports which are not in compliance with the Convention and reported limited capacity to enforce trade-related laws and regulation at the national level, resulting in illegal or informal trade being carried out within their territories, and the availability on the market of mercury from unreported sources. …".

[183] "With no international instruments governing trade in lead paint, the responsibility falls to the national level. Nearly one-third of countries impose lead paint controls […] Fifteen per cent of these countries, however, do not regulate lead paint imports […] In addition, national legislation banning trade in lead paint often allows exemptions for industrial uses, and the paint can end up in consumer markets in countries with weak or poorly enforced regulations." (pp. 24-25)

- Over time, a huge amount of mercury pollution – estimated at 350 thousand tons in total – has been emitted into the atmosphere as a result of human activities, with the largest proportion of this occurring from the second half of the 19th century onwards. Since the middle of the last century, as part of the global socioeconomic process known as the 'Great Acceleration', mercury-related applications and environmental emissions have increased rapidly (Figure 1) [UWE, 2017; Streets et al., 2011].

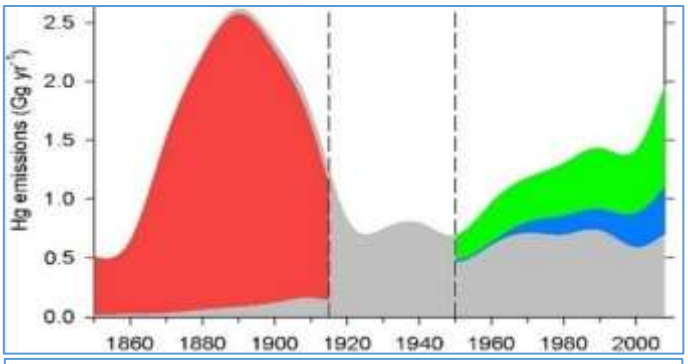

Fig. 1 Periods of change in anthropogenic mercury emissions (Gg/yr): (i) 'Gold Rush' ■ (ii) World Wars and 'Great Depression' ■ (iii) 'gold panning' during the Great Acceleration ■ and coal use ■ [UWE, 2017; Streets et al., 2011]

- For the time being, the mining and use of mercury and global anthropogenic atmospheric emissions of mercury pollutants continue to grow, the latter currently amounting to approximately 2000-2500 t/year [UNEP/GMA, 2019]. Of this, the proportion of emissions originating in Asia, in particular, has risen. Among the sectoral sources that utilize this substance and are responsible for its environmental releases, gold mining (ASGM) accounts for the largest share, followed by coal combustion (of course, in terms of emissions), and in addition, the amount of mercury involved in the production of VCM is still considerable [UNEP/GMA, 2019; UNEP/GCO, 2019]. This latter industrial procedure has been discontinued in most countries but is ongoing in China, India, and Russia, although the possibility of switching to mercury-free technology in this production process is already available and has been introduced in many other countries [UNEP/GMA, 2019].[184]

- The rate of the further decrease of human-induced mercury pollution largely depends on the proper implementation and (possible) future tightening of the global agreement, which is why only very conditional and divergent scenarios and estimates may now be prepared [MCM/PR, 2023; Selin & Selin, 2022; Geyman et al., 2024]. The most uncertain factor is the prospect of the end of mercury use in gold mining (ASGM) [MCM, 2023b].[185] Addressing completely the 'mercury problem' is also subject to the compliance of countries with some other environmental agreements, such as the *Paris Agreement* on climate change, as the elimination of coal combustion would also bring about a remarkable reduction in mercury emissions [Brocza et al., 2024[186]].

- Among the mercury applications to be phased out, one in particular stands out: the use of dental amalgam is unchanged in the majority of developing countries that participated in the recent survey by the World Health Organization [WHO, 2021]. This may also be one of the reasons why a number of developing countries have not yet acceded to the *Minamata Convention on Mercury*.

In relation to lead and cadmium, the evaluation of the effectiveness of policies and measures at the global level is even more complicated, especially due to the lack of a global regulation. Nevertheless, some conclusions can be drawn based on various data sources.

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[184] "Emissions from intentional use of Hg in the chlor-alkali industry have been decreasing for some time in most areas of the world. In part this is due to increased attention to best practices to reduce emissions, but is primarily due to the shift from production based on the Hg-process to membrane production technology." (pp. 3–26)

[185] "1. Artisanal and small-scale gold mining continues to be the sector responsible for the largest use, emissions and releases of mercury globally, with significant impacts to human health, land, ecosystems and biodiversity."

[186] "Hg emission projections until 2050 show noticeable reductions in combustion sectors for all scenarios due to a decrease in global fossil fuel and traditional biomass use, leading to emission reductions of 33 % at baseline and up to 90 % when combining stringent climate controls and the most efficient Hg controls." (p. 7385)

- The level of lead mining and utilization has essentially remained unchanged, but half of the total amount required for various applications is already available from recycling. Lead obtained from mining comes mainly from Chinese mines. Globally, by far the largest quantity of lead is still used in lead-acid batteries, and estimates suggest that this amount will continue to increase, along with the resulting injurious health and environmental implications [ILZSG, 2018, 2020; UNEP/GCO, 2019; BRC, 2019[187]]. According to the most recent data, lead mining production accounts for about 4.5Mt/year, 1.5 times more than three decades ago [ILZSG, 2023; SRD, 2024].
- At the same time, it is a major achievement that the use of lead additive in gasoline has finally ended worldwide, thanks to an increase in awareness about its dangers and the introduction of certain technical innovations (modification of the petroleum refining process and adding another compound to gasoline for the same purpose) [OECD & UNEP, 1999[188]; PCFV, 2010; UNEP, 2021c[189]].
- With respect to cadmium, let us first refer to some trends that indicate the difficulties in making an international-level assessment and defining relevant actions related to this toxic chemical: (i) the primary use of cadmium is in the manufacturing of NiCd dry batteries and this is tending to decrease, while the demand for cadmium in other applications is increasing; (ii) although comprehensive national regulations are in place, primarily in developed countries, cadmium-induced health problems remained a serious concern around the world [UNEP/GCO, 2019; WHO, 2019[190]]. The general complications of tackling these challenges are summarized very clearly in a recent UNEP report: "Substantial progress has been made in managing cadmium, as shown in the decrease of cadmium emissions and levels in air in some parts of the world. However, these existing efforts are likely still inadequate to eliminate or minimize cadmium exposures from anthropogenic sources globally as a whole […]. Emissions from growing coal combustion, metal smelting and other sources are quickly increasing in some parts of the world. […] Addressing cadmium can be complex, not only due to the diversity and prevalence of sources around the world, but also due to many other factors. For example, cadmium is not mined on its own, but rather produced as a by-product of zinc; this means that simply reducing cadmium demand by restricting or banning its use may not effectively limit its global production." [UNEP, 2020c: p. 74]

[187] "Global lead mine production is projected to grow between 2018 to 2022, fueled by increased demand for lead acid batteries from the automobiles and electric bikes sectors, especially from China and the US."

[188] "If lead is not added to gasoline, therefore, it is necessary to either modify the refinery process to raise the octane level of the unleaded gasoline pool or to add alternative octane enhancing additives or to reduce the vehicle octane requirement. In most countries, a mixture of the first two approaches is applied." (p. 5)

[189] "2021 marked the end of leaded petrol after an almost 20-year campaign by the UNEP-led Global Partnership for Clean Fuels and Vehicles. Banning the use of leaded petrol in ground transport has been estimated to prevent more than 1.2 million premature deaths per year, increase children's IQs, save USD 2.45 trillion a year for the global economy and decrease crime rates." (p. 16)

[190] "[H]uman activities, such as tobacco smoking, mining, smelting and refining of non-ferrous metals, fossil fuel combustion, incineration of municipal waste (especially cadmium-containing batteries and plastics), manufacture of phosphate fertilizers, and recycling of cadmium-plated steel scrap and electric and electronic waste; remobilization of historic sources, such as the contamination of watercourses by drainage water from metal mines or from waste sites. Cadmium releases can be carried to and deposited on areas remote from the sources of emission by means of long-range atmospheric transport." (p. 1)

- Currently, world cadmium refinery production is circa 23-24kt/year (about 30% more than three decades ago), and the trend is toward an increase [Garside, 2020; ICDA, 2021; Han et al., 2022; USGS, 2024]. Overall, the global demand for and market of cadmium is expected to expand further, along with an anticipated slight increase in its production despite growing awareness of the health and environmental risks of this toxic chemical [MRC, 2020[191]; USGS/ReportLinker, 2024].

Considerable progress in the pan-European region in terms of phasing out the employment of these substances is demonstrated by the following accomplishments:

- at least in this region (i.e., in the UNECE countries), lead and mercury have 'disappeared' from many products to be replaced by lead- and mercury-free alternatives, and leaded gasoline is no longer on the market;
- thanks to the effective implementation of the UNECE protocol covering all three toxic heavy metals, so far, their anthropogenic emissions have been significantly reduced in this region (Figure 2) [EMEP, 2019; EMEP, 2022].

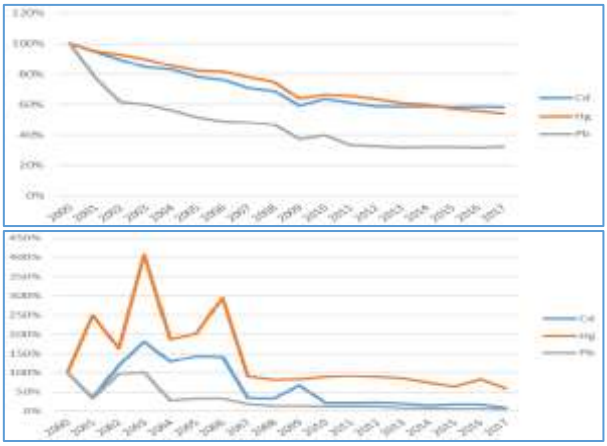

Figure 2 Changes in heavy metal emissions in the pan-European region: – cadmium, – mercury, – lead (% compared to the level in 2000; based on data from countries that have acceded to the protocol on heavy metals; above: situation in the Western region of EMEP, below: situation in the Eastern region) [EMEP, 2019]

1.4.4. The need to strengthen the science-policy interface

As a result of intensified international efforts in recent decades, attention has grown to issues related to hazardous chemicals in general and heavy metals in particular, and the commitment to tackling these problems has also strengthened. However, it has become clear that the in-depth assessment of the use of these substances, their consequences, and more effective interventions for coping with the associated implications require more extensive research, interdisciplinary collaboration, better scientific communication, the further advancement of institutional frameworks, and an improved science-policy interface.

Development of scientific cooperation and activities. Diversified research on the topic of heavy metals has been launched, and new institutions have been established to support inter- and multidisciplinary cooperation.

- Scientific findings that increasingly clearly indicate the harms induced by numerous chemicals, such as toxic heavy metals, have not sufficiently affected the 'world of politics' for a long time, i.e., they have had a limited impact on decision-makers. The International Panel on Chemical Pollution (IPCP), established in 2008, investigated the reasons for this. According to their analysis, the scope of tasks and activities of the existing organization (IOMC) should be expanded, or a new intergovernmental body should be established with the involvement of representatives of science [IPCP, 2019]. This would allow researchers to contribute more directly and effectively to the further improvement of international agreements and programs containing appropriate goals, policies, and measures, including those for toxic heavy metals. (This would follow the 'model' of such bodies working on

[191] "[The] cadmium market is to grow at 2-3% in the near future; rechargeable nickel cadmium batteries will continue to be the leading consuming segment".

climate change and biodiversity, such as the IPCC and IPBES.) Finally, in March 2022, the UNEP General Assembly adopted a resolution to form such an expert body, the Science-Policy Panel (SPP), to promote the sound management of chemicals and waste and to assist in the elaboration of the new chemicals strategy [UNEP, 2022].[192] In the same month, the Parties to the *Minamata Convention on Mercury* established their own scientific advisory board [MCM, 2022].[193]

- The preparation of the new chemicals framework strategy, intended inter alia to establish better interdisciplinary cooperation and improve the science-policy interface, could begin only after some delay.[194] This new policy set is also aimed at better harmonizing the sound management of chemicals with the policy framework for the biodiversity convention (CBD), the relevant health program and regulations (WHO), instruments on occupational health for the protection of workers from toxic substances (ILO), and the code of conduct on pesticide management (FAO). The toxic heavy metals were also explicitly in focus: "Consider collaboration and joint research on topics including: […] (iv) lead paint, cadmium, etc. […] identify priority pollutants based on key scientific and technical assessments, including […] cadmium, triclosan, mercury and other heavy metals …" [SAICM, 2020: pp. 5, 28]. Eventually, the *Global Framework on Chemicals* was adopted in 2023 and highlighted the importance of such interconnections [UNEP/GFC, 2023: Target E6, par. 88].
- In order to facilitate the implementation of the actions on mercury, UNEP supported the expansion and strengthening of the Global Mercury Partnership [MCM, 2021b].[195] The WHO expert panel has formulated new recommendations to prevent and mitigate the harmful health effects of cadmium [WHO, 2019].[196]

The relationship between the conventions and their governing bodies. The four global chemicals-related conventions, the *Rotterdam, Stockholm, Minamata Conventions,* and the *Basel Convention* on hazardous chemicals and wastes, address different but closely interlinked issues regarding toxic heavy metals.

- Before the decision to develop a convention dedicated to the toxic heavy metals was made, it was suggested that instead of creating such a new global legal instrument for these substances, adequate regulation could be achieved by expanding the 1989 *Basel Convention* or the 1998 *Rotterdam Convention*, or perhaps the 2001 *Stockholm Convention* on persistent organic pollutants. In the end, this idea was dropped, and instead, a new separate convention was passed, but only on mercury.
- In the meantime, the Parties to the three aforementioned conventions decided in 2008 that their treaty bodies would closely cooperate (by also setting up a joint secretariat). The *Minamata Convention* 'relied' on the procedures of the *Basel Convention* concerning mercury wastes, and it was also suggested that the coordinating institutions of the mercury convention should join the cooperation referred to above, established in association with the previously developed chemical conventions [NCM, 2017]. The new chemicals policy framework has re-

[192] Resolution UNEP/EA.5/Res.8: "Science-policy panel to contribute further to the sound management of chemicals and waste and to prevent pollution".

[193] Open-Ended Scientific Group (OESG).

[194] The COVID-19 pandemic has not only affected some environmental pollution processes, but also the related international policy collaboration (like many other international matters), including the coordination of the implementation of the mercury convention and the development of a new chemicals strategy for the post-2020 period.

[195] "[T]he focus of work of the Partnership has been updated to reflect that it aims at supporting timely and effective implementation of the Convention; providing state of the art knowledge and science on mercury". (p. 4)

[196] "To decrease global environmental cadmium releases and reduce occupational and environmental exposure to cadmium and associated health effects […]. Reduce, as far as is practicable, emissions of cadmium – particularly into surface waters – from mining and smelting, waste incineration, application of sewage sludge to the land, and use of phosphate fertilizers and cadmium-containing manure. […] Promote the elimination of use of cadmium in products such as toys, jewellery and plastics." (p. 4)

emphasized that these links can help to take into account the interrelations between these global problems and strengthen synergies between their solutions [UNEP/GFC, 2023: par. 39].[197]

- The scope of the UNECE *Protocol on Heavy Metals to the Convention on Long-Range Transboundary Air Pollution* (CLRTAP) covers environmental pollution caused by mercury, lead, and cadmium. Because of the long-range atmospheric transport of these pollutants, this hazardous process does not only affect the pan-European region (as explained before), thus the post-2020 strategy for the implementation of this convention also highlighted the importance of cooperation with the governing bodies of the aforementioned global agreements (including the *Minamata Convention on Mercury*) and other international organizations (e.g., UNEP and WHO) [CLRTAP, 2018[198]; CLRTAP, 2019[199]].

1.5. CONCLUSIONS AND LESSONS LEARNED

The history of the applications of toxic heavy metals,
and the recognition and mitigation of their harmful effects

> "Some of the heavy metals and non-metallic minerals […] pose serious hazards to health and the environment. Various hazardous products and processes are already built into current systems of production and the technological structure of contemporary society, and it will be a long time before these can be replaced with less dangerous, inherently safer technologies and systems."
>
> *Our Common Future, 1987*[200]

Based on the analysis of the process of scientific recognition and political acknowledgment of health and environmental problems resulting from the utilization of toxic heavy metals, as well as the development of international cooperation on this subject, a number of conclusions and lessons can be drawn which might also be important in dealing with other and/or future large-scale hazardous environmental issues. That is, in other such cases, inter alia, the cause-and-effect relationships can be clarified, and the necessary actions can be determined at the international level through identifying similar contradictions and twists and turns.

With mercury, lead, and cadmium, paradoxical situations arose that proved to be very useful in many ways and particularly harmful at the same time. Representatives of health and environmental science played a prominent role from the 1960s and 1970s in the exploration of the former and the demonstration of their global reach.

- This controversial situation with mercury and lead had existed for thousands of years because, on the one hand, their injurious influences were not (or not properly) identified, and on the other

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[197] X. Institutional arrangements: "73. With respect to the Framework and its implementation, the functions of the International Conference will be: […] (d) To promote cooperation and coordination among international instruments and programmes relating to chemicals and waste; […] 77. When appropriate, sessions of the International Conference should be held back to back with meetings of the governing bodies of relevant intergovernmental organizations in order to enhance synergies and cost-effectiveness."

[198] "5.(a) The Convention takes into consideration the global context of international cooperation to reduce air pollution […] 15. The Convention also developed protocols that address persistent organic pollutants and heavy metals, including lead, cadmium and mercury. This leadership has paved the way for a global approach to these problems and inspired the Stockholm and the Minamata Conventions."

[199] "6. We welcome the establishment of a forum for international cooperation on air pollution […], focusing on exchange with other regions and working closely with other relevant initiatives, in line with the objectives of United Nations Environment Assembly resolution 3/8 on preventing and reducing air pollution to improve air quality globally."

[200] Report of the World Commission on Environment and Development [WCED, 1987: excerpt from para. 66]

hand, it did not seem to be a sufficient justification for giving up the benefits of their use when certain concerns did arise. As with many other occasions of use of some special substances or procedures throughout history, arguments that the respective dangers were non-existent or negligible compared to the advantages derived from those applications and practices could only be countered by demonstrating/proving the serious consequences and presenting the factual data to substantiate them.

- Observations and scientific studies conducted within international frameworks have become of decisive significance in detecting the adverse impacts attributable to these toxic substances and in initiating recommendations, programs, or agreements aimed at restricting their application and reducing/eliminating their harm.

In order to address at least the most critical issues arising from those applications and products that use toxic heavy metals or their compounds and to reduce the environmental emissions of such hazardous pollutants, coordinated international interventions, as defined in programs and agreements, in addition to the measures of individual countries and companies, have been and will be necessary. The preparation of these international instruments has been influenced by a number of factors that facilitated or hindered the achievement of reaching a consensus about them, including (i) the assessment of whether they are required at all or are urgently needed and (ii) in the latter case, the definition of specific goals and substantial provisions.

- The development of such international policy and legal instruments containing goals, tasks/obligations and means facilitating their implementation has been made difficult, especially due to the rather different situations of individual countries or specific groups thereof with regard to the applications of these toxic substances, their harmful impacts, and even the knowledge about the latter.

- International recommendations and regulations on toxic heavy metals have had essential environmental policy precedents. As regards the 2013 *Minamata Convention on Mercury*, some guidelines, conventions, programs, and certain elements thereof dealing with the use and international trade of hazardous chemicals and wastes can be considered as such (*Cairo Guidelines*, 1987; *Basel Convention*, 1989; *London Guidelines*, 1989; *Rotterdam Convention*, 1998; global chemical strategy, 2006). Similarly, in the new rounds of negotiations, previous 'patterns' of compromises could be reiterated (perhaps with some reasonable modifications/corrections), or previously adopted agreements could be effectively relied on. The latter situation is clearly reflected in the *Minamata Convention*, which required the application of the *Basel Convention* to hazardous wastes containing mercury.

- The primary conditions for enacting these international regulations are that (i) they 'enter into force' after their adoption, (ii) States commit themselves to their fulfillment, and (iii) develop the national action plans in compliance with the jointly approved international goals and provisions and, in particular, accomplish their own commitments. However, many States have not yet become Parties to agreements specifically dealing with these toxic heavy metals, namely, the global *Minamata Convention* and the relevant UNECE protocol (CLRTAP/HM). Similarly, a lack of commitment is indicated by assessments according to which many States did not reflect the targets in their national-level regulations/plans or did not take relevant measures concerning the toxic heavy metals in line with the provisions of the global chemicals strategy, the sustainable development agenda or the convention on mercury [UNEP/GCA, 2019: pp. 19, 45; UN/DESA, 2024: p. 32; MCM/PR, 2022: p. 7].

The effective implementation of these international instruments has been and continues to be hampered by several specific considerations and procedures ('solutions'). We highlight two of these here.

- In terms of toxic heavy metals, one of the fundamental obstacles to effectively implementing the relevant international recommendations and regulations and setting new and more ambitious

targets is so-called 'technological inertia' (or 'lock-in', including consumers' lock-in). The usual arguments against transitioning to less hazardous processes and products include the following: (i) that 'proven' (customary) production and consumption practices are safe and cost-efficient if the conditions of their uses are adhered to; and (ii) that the application of technologies and the manufacturing of products free from these heavy metals and/or the environmental releases of such pollutants are inefficient, more costly, and may cause other problems. Some well-known examples of this 'inertia' comprise the mercury-based procedure for VCM production, artisanal and small-scale gold mining (ASGM), and the ongoing prevalence of NiCd batteries in many countries.

- Countries may meet their national commitments – but this does not contribute to the mitigation of hazards at the global level – if activities that pose adverse environmental and health effects are 'relocated' (outsourced) to other countries. More concretely, such a 'solution' has been that while many countries have halted the manufacturing of PVC by means of a mercury (actually involved in the production of its raw material, VCM), this plastic material is purchased and imported from other countries that still use the mercury-based procedure (in which both these production activities and mercury pollution are increasing).

There remains a large gap between some of the goals recommended by science and those approved by policymakers to address this global problematic*,* despite the increasing amount of observational and scientific information on the adverse health and environmental effects of these toxic substances.

- The ultimate objective of health and environmental policy has become the elimination of harms resulting from human activities associated with lead, mercury, and/or cadmium and causing the environmental release of such toxic pollutants. To this end, various products and industrial processes must be 'freed' from these toxic chemicals (i.e., by transitioning to lead-free, mercury-free, and cadmium-free procedures). Considering the different situations, interests, and possibilities for intervention of the countries, 'intermediate' goals have also been accepted, based on significant compromises and providing temporary options for exemptions, but even these are not being met at the pace that would follow from the recommendations formulated by the relevant scientific bodies.[201]

- The inadequate implementation of programs and agreements may further deepen the gap between science and policy. This applies equally to the problems caused by 'legacy mercury', phasing out the use of these toxic heavy metals, reducing their environmental emissions, and preventing their entry into the waste stream. (i) "Human activities have increased total atmospheric mercury concentrations by about 450% above natural levels. This increase includes the effects of mercury emitted from human sources in the past, which is still circulating in the biosphere and is known as legacy mercury." [UNEP/GMA, 2019: p. 3; UNEP, 2021a]. (ii) "[H]azardous waste and more specifically e-waste contain hazardous substances such as lead, cadmium, mercury […]. The capacity for environmentally sound management of such hazardous waste is still lacking in many developing countries and countries with economies in transition" [UNEP, 2021b: p. 76].

- It took several years to start the first comprehensive evaluation of the environmental effectiveness of the mercury convention, and its preparation is still progressing slowly, as relatively little time

[201] Among other things, such significant science-policy gaps are reflected (i) in the compromises set in the *Minamata Convention* on dental amalgam and mercury use in gold mining (ASGM); (ii) in the conditional requirements of the *African-Eurasian Migratory Waterbird Agreement* on phasing out the use of lead shot for hunting in wetlands by the Parties ("as soon as possible in accordance with self-imposed and published timetables") and (iii) by the fact that no global agreement could be concluded on lead and cadmium.

has passed since the adoption and the entry into force of the convention [MCM, 2021a[202]; MCM, 2023c[203]]. Moreover, due to the numerous compromises regarding the deadlines for implementation of some of the key targets, a thorough, global-level evaluation can only be expected after a longer period of time. In comparison, the effectiveness of the pan-European 'heavy metal' agreement can already be somewhat more clearly demonstrated, as indicated above [EMEP, 2019; EMEP, 2022: pp. 19-20].

- Over time, stricter targets, obligations, and more effective instruments may be defined as a result of reviewing the appropriateness and sufficiency of existing regulations and their implementation. A good example of this was the amendment of the *Basel Convention* (1995). Such progress was made in the case of the *Minamata Convention on Mercury* when the Parties decided to phase out the production and trade of some mercury-added products by 2025 (e.g., compact fluorescent lamps) [MCM, 2022].[204]
- In view of all this, international expert bodies that deal primarily with the environmental and health dimensions of this critical area are understandably urging the development of a global monitoring and assessment system that covers the environmental releases and harmful impacts of these toxic pollutants, and more effective risk reduction measures than before [Lancet, 2022].[205]

* * *

The tasks associated with toxic heavy metals are directly linked to the global sustainable development agenda, its numerous goals, and target areas [UN, 2015; NCM, 2017; SAICM, 2020; MCM/PR, 2022[206]; GFC, 2023: par. 6, Annex II par. (u)/(ix)]. However, in order to meet these general sustainability objectives, more work is needed on these heavy metals than before: more effective implementation and further tightening of the relevant international programs and agreements, as well as a more ambitious and comprehensive global strategic approach that covers these substances (also taking into account the interlinkages with various socioeconomic issues).

[202] "[T]he Conference of the Parties evaluate the effectiveness of the Convention beginning no later than six years after the date of entry into force of the Convention […] (d) Consider establishing an effectiveness evaluation committee tasked with preparing a report on the effectiveness of the Convention and overseeing scientific and technical work in that regard; (e) Consider the indicators for evaluating the effectiveness of the Convention".

[203] "1. In decision MC-4/11, the Conference of the Parties agreed to begin the first effectiveness evaluation of the Minamata Convention on Mercury. […] 5. The Conference of the Parties also decided to continue consideration of two matters at its fifth meeting, namely: (a) The timeline of the first effectiveness evaluation; (b) The terms of reference of the effectiveness evaluation group".

[204] Decision MC-4/3: Review of and amendments to annexes A and B to the Minamata Convention.

[205] "We present specific recommendations for pollution and health, building on the earlier recommendations in the Lancet Commission on pollution and health. […] International organisations need to revise pollution tracking for the SDGs to correctly represent the effect of chemicals pollution including heavy metals. […] International organisations and national governments need to invest in generating data and analytics to underpin evidence-based interventions to address environmental health risks." (p. 544)

[206] "Joining the Convention [on mercury] allows a party to […] contribute to achieving its commitment to Sustainable Development Goals".

2. GLOBAL HAZARDOUS CHEMICAL POLLUTION AND WASTE FLOWS

THE SPREAD OF A MULTITUDE OF PERILOUS CHEMICALS AND POLLUTANTS TO ALL CORNERS OF THE GLOBE

UN Globally Harmonized System: pictograms for substances hazardous to human health and the environment and for general hazards

"The most alarming of all man's assaults upon the environment is the contamination of air, earth, rivers, and sea with dangerous and even lethal materials."

Rachel Carson, 1962[207]

"Will modern man reach Mars while standing up to his knees in the garbage of Planet Earth?"

Barbara Ward & René Dubos, 1972[208]

"Chemicals are part of our everyday lives. […] However, if poorly used and managed, hazardous chemicals and waste threaten human health and the environment."

Joyce Msuya, 2019[209]

The increasing and often inefficient processing and use of resources derived from nature, the production of 'artificial' substances, as well as the disposal of such materials and products containing them after they become redundant, have led to rapidly growing global pollution and volumes of hazardous waste.

As a result of human activities, such materials in various states enter the environment in many ways and can reach areas even far from their place of production, use, or source of unintentional emission. The subject of this chapter is the environmental burden caused by various contaminants, primarily hazardous ones of different types, consistence and that have harmful effects.

Those components of this broad problematic are reviewed and analyzed that have a significant international context, have also been studied by scholars in this regard, and have led to the formulation and adoption of international policy responses and legal instruments.

[207] Silent Spring [Carson, 1962: p. 6]
[208] Only One Earth [Ward & Dubos, 1972: p. 131]
[209] Foreword by the Executive Director of UNEP [UNEP/GCO, 2019: p. vi]

2.1. THE GLOBALIZING POLLUTION AND WASTE PROBLEM

2.1.1. Increasing environmental contamination and the need to halt this hazardous process: scientists' warnings and concepts

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2.7. CONCLUSIONS AND LESSONS LEARNED

2.1. THE GLOBALIZING POLLUTION AND WASTE PROBLEM

2.1.1. Increasing environmental contamination and the need to halt this hazardous process: scientists' warnings and concepts

Realization of the severity of the problem. Historical records show that municipal waste and sewage were 'disposed of' in a rudimentary manner in earlier times, and this sometimes led to epidemics. Later on, the even more critical and difficult issue to deal with became the hazardous wastes and pollutants released into the environment in growing volumes with the advent of the industrial era (the 'industrial revolution') and the accelerated use of various natural resources: "Overall, 2470 Gt or 72% of all materials extracted since 1900 have been returned to the environment as waste and emissions." [Krausmann et al., 2018: p. 136]

- Even early in human history – at least in larger settlements – the safe management/disposal of municipal waste should have been ensured due to the direct and serious health risks it posed. However, it was only at the end of the 19th century that the organized collection and treatment of this waste began in some large cities [Worrell & Vesilind, 2012].[210]
- This is remarkable from today's perspective and in the current situation, as Vance Packard described and analyzed in detail the consequences of the 'wasteful' consumption patterns that have become widespread in the most developed countries many decades ago, in his book *The Waste Makers* [Packard, 1960: p. 10]: "Prodigality is the spirit of the era. Historians, I suspect, may allude to this as the Throwaway Age."
- Environmental contamination has accelerated and become of global significance, as besides the (inadvertent) production of growing volumes of more or less hazardous wastes, the environmental release and long-range transmission of harmful pollutants have also rapidly increased since the middle of the last century. Barbara Ward and René Dubos highlighted this dangerous globalizing process in their landmark book *Only One Earth* so many decades ago: "The surge of demand began gobbling up resources and increasing requirements of materials and energy at an unprecedented rate. The economy responded rapidly to these signals. New energy-producing equipment was installed, materials mobilized, sold, used and junked. […] Moreover, the sheer scale of effluents to be disposed of and materials to be junked […]. Nor has this burden simply proved to be an intensification of earlier pollution. It has also changed in character. The very freedom of recently invented technologies to devise, manipulate and create new substances in the wake of chemical discovery has added a still unmeasured element of risk to the effluents of massively expanding industrial systems." [Ward & Dubos, 1972: (v) The Consumer Revolution, pp. 60-62] Their latter remark may remind us of the fast evolution of the chemical industry, specifically 'synthetic organic chemistry', involving the invention and then massive production of numerous synthetic compounds which were also intentionally (as e.g., pesticides) or inadvertently released into the environment.
- The global assessment and vision of the Club of Rome stressed the threat of an exponentially increasing quantity of pollutants and waste [Meadows et al., 1972][211], presenting its major sources and proposing solutions that could bring an end to this trend and re-achieve a proper 'state of

[210] "Finally, in 1866, 200 years after the first attempt at cleaning up the streets, the Metropolitan Board of Health in New York declared war on trash, forbidding the throwing of garbage or dead animals into streets. The first incinerator in the New World was built in 1887 on Governor's Island in New York." (p. 2)

[211] "The wastes of human civilization can build up in the environment until they become visible, annoying, and even harmful. Mercury in ocean fish, lead particles in city air, mountains of urban trash, oil slicks on beaches-these are the results of the increasing flow of resources into and out of man's hands. It is little wonder, then, that another exponentially increasing quantity in the world system is pollution." (pp. 68-69)

equilibrium', thereby stopping the growth of harmful environmental releases and impacts. Also, in other studies since the 1970s onwards attention was drawn not only to the globalizing waste problem in general, but to the increase in the amount of hazardous wastes, moreover, even to the appearance of plastic pollution in the environment.

- The research group led by Nobel laureate Dénes Gábor delved even deeper into waste prevention and environmental pollution reduction opportunities that would also promote more efficient resource management in the fields of energy and materials management, as well as agriculture. Their general conclusion was that waste production and environmental damage resulting from the inefficient ('wasteful') use of natural resources cannot continue in the current manner, and a much more responsible approach is needed in this area. "The world is at a new and critical stage. […] Our consumer-oriented industrial society has irresponsibly exploited the world's non-renewable and easily accessible mineral resources. It has destroyed enormous areas of once fertile land. In many places we have endangered and killed life by the pollution of air and water. […] The Problem of Waste. The analysis made in this report has emphasized the trend in today's society to waste the precious natural resources of energy, raw materials and food; and has illustrated how technologies – even the most advanced ones – are in many cases intrinsically wasteful. […] In this situation the need for reducing waste in order to prolong the availability of natural resources and to limit environmental damage has become indispensable." [Gabor et al., 1976: pp. 1, 212].
- Along the same lines, more and more research studies were published. The essence of their general 'message' is that in the waste and pollution-prevention/decreasing strategy the aim is primarily to reasonably minimize and more efficiently use (raw) materials. "Though the symptom gets attention, politicians rarely diagnose the disease: a global economy built on the inefficient use of raw materials and energy. […] Garbage output continues to grow (often faster than population), as does the environmental damage from waste disposal […]. From the attempts of people around the world to find alternative solutions to waste problems, a 'soft materials path' can be mapped out. Its operating principle is efficiency: meeting people's needs with the minimum amount of the most appropriate materials available. […] Many modern consumer products also contain toxic substances that can pose disposal problems: batteries contain heavy metals such as lead, mercury, and cadmium; household cleaners, solvents, paints, and pesticides often include hazardous chemicals." [Young, 1991a: pp. 6, 15; Young, 1991b].
- This conceptual approach was generalized by other researchers by reviewing the diverse and expanding 'material and energy exchange' between nature and society, the social (or socioeconomic) metabolism, a concept that not only pinpoints the problems stemming from the overuse (overexploitation, overconsumption) and unsustainable processing of natural resources, but also the escalation in the amount of waste and emission of pollutants [e.g., Krausmann et al., 2018 and Görg et al., 2020: p. 44]: "The social metabolism is at once generalizable and highly specific to the society in question. At the national level, industrialized societies, for example, obtain their required material and energy inputs both from domestic agriculture, forestry and mining and from imports; they dedicate a high and increasing share of these inputs to stock-building, produce large amounts of wastes and emissions and export materials and energy to other societies on the output side."
- The even more complex model of the 'circular economy' also started to be theoretically established long ago [e.g., Boulding, 1966], then gradually received much greater attention [e.g., Pearce & Turner, 1990: pp. 35-39]: "Waste arises at each stage of the production process. […] Production creates waste in the form of industrial effluent and air pollution and solid waste; final consumers create waste by generating sewage, litter, and municipal refuse. […] The environment has a capability to take wastes and to convert them back into harmless or ecologically useful products. This is the environment's assimilative capacity. […] So long as we dispose of waste in quantities (and qualities) that are commensurate with the environment's assimilative capacity, the circular economic system will function just like a natural system".

- One consequence of the higher costs of the gradually more stringent waste management regulations in developed countries since the 1970s has been the rising volume of waste shipments to the latter – taking advantage of the non-existent or much looser regulations in the receiving countries [Hackmann, 1994]. This practice was sometimes replaced or supplemented by the 'solution of disposing of' (i.e., sinking) waste, especially hazardous waste, in maritime areas outside national jurisdiction (in the high seas) [Faragó, 2013; Rakonczai, 2019[212]]. As mentioned in the introductory chapter of the present book, it was not only waste that set off on such a 'migratory journey'. Taking advantage of the lack of occupational health and environmental regulations in some developing countries (and the existence of some local 'interests'), the opportunity opened up for the relocation (outsourcing) of some production, frequently also involving serious environmental pollution and the generation of hazardous waste. Conflicts over hazardous waste transported across national borders and 'abandoned somewhere' forced the international control/regulation of these waste management procedures (see subsections 2.3 and 2.4).

2.1.2. Strengthening international science-policy interaction to respond to the globalizing pollution and waste-related anxiety

The realization of the urgency of formulating global-level responses to escalating environmental contamination catalyzed the intensification of critical assessment activities and the formulation of pertinent recommendations within the framework of international organizations, also facilitated by the improvement in the world political atmosphere from the late 1980s onwards.

- The increasing environmental 'side effects' accompanying the development of agriculture, industry, transport, and human settlements were identified together with calls for the necessary actions by the participants of international meetings held in 1971 (Founex, Switzerland) and 1974 (Cocoyoc, Mexico).
- The report adopted in 1971, inter alia, referred to "chemical pollution: arising out of air pollutants, industrial effluents, pesticides, metals, and detergent components and similar agents" and recommended "that Governments, FAO and WHO, in cooperation with UNESCO and IAEA, strengthen and co-ordinate international programmes for integrated pest control and reduction of the harmful effects of agro-chemicals […] and that Governments, and the Secretary-General in co-operation with FAO and other UN organizations concerned, as well as development assistance agencies, take steps to ensure international co-operation in the research, control and regulation of the side effects of national activities in resource utilization where these affect the aquatic resources of other nations: [through the] discharge of toxic chemicals, heavy metals, and other wastes may affect even high-seas resources" [UN, 1971: pp. 11, 58, 72].
- The 1974 meeting was basically devoted to the differing situations and responsibilities of the developed and developing countries concerning, among other matters, escalating pressures on environment, and it was made clear, e.g., that "the cheapness of materials has been one factor in increasing pollution and encouraging waste and throwaway economy among the rich. […] Low waste and clean technologies should replace environmentally disruptive ones." [UNCTAD-UNEP, 1974: pp. 2, 6].
- The *Action Plan* adopted at the 1972 UN Conference on the Human Environment not only addressed in general the pollution, chemicals, and waste related problems (including especially the hazardous agricultural, and radioactive wastes), but also listed recommendations for more in-depth monitoring and studying these issues. Furthermore, as one of the urgent steps, it was

[212] "The diverse level of severity of environmental regulations in countries has also made the waste problem a global one. The high cost of hazardous waste management has 'encouraged' owners to look for cheaper options for disposal. This led to marine disposal and later practices disguised as 'waste trade'." (p. 203)

recommended to "[d]evelop plans for an International Registry of Data on Chemicals in the Environment based on a collection of available scientific data on the environmental behaviour of the most important man-made chemicals and containing production figures of the potentially most harmful chemicals, together with their pathways from factory via utilization to ultimate disposal or recirculation" [UN, 1972: Recommendation 74(c)].

- In addition to organizations that have been dealing with specific types of waste in accordance with their own mandates for some time (WHO, FAO, IAEA), this topic was included in the first *Action Plan* of the UN Environment Programme – shortly after its establishment in 1972. Among the many elements of this plan, the suggested actions included those of establishing a global environmental monitoring system for the "monitoring of pollutants of common concern in the air, water, food, soil and […] assessing their effects" and specifically dealing with atmospheric and marine pollution [UNEP, 1973: A.36.(i), B.39.(i), C.46].
- Initial concrete achievements by UNEP comprised the compilation of the first *State of the Environment* in 1975 and the establishment of the International Register of Potentially Toxic Chemicals (IRPTC) in 1976, which assisted in the assessment and control of the hazards that chemicals pose to human health and ecosystems. The former highlighted the increasing pollution and waste-related issues besides expressing concern about the "damage to the environment and to health that can result from the continuing increases in the use of chemical pesticides and fertilizers" and "the introduction into the environment of more than a thousand new man-made chemical compounds every year" [UNEP/SoE, 1975: pp. 8, 15].
- The 1980s saw a significant turning point in this area, when, in parallel, between 1983 and 1987, an expert group commissioned by UNEP developed a comprehensive environmental assessment and a series of proposals, and the World Commission on Environment and Development (WCED) implemented wide-ranging analyzing work and formulated a large number of recommendations. In both cases, the overall objective was to contribute to the achievement of broadly defined sustainable development. UNEP presented its report entitled *Environmental Perspective to the Year 2000 and Beyond*, and WCED submitted its one entitled *Our Common Future* to the UN General Assembly, which adopted both in 1987. The authors of these documents, among other unsustainable processes, examined the growing international problems of pollution, hazardous wastes, and chemicals and concluded that adequate policies and measures for responding to these challenges must be determined and introduced as soon as possible [UNEP, 1987[213]; WCED, 1987[214]].

* * *

The problem of increasing pollution and waste generation has become globalized. This is particularly valid for hazardous contaminants, together with their harmful health and environmental influences. The above-mentioned assessments, concepts, and recommendations by researchers and international bodies served to widen the theoretical and science-based foundation for the elaboration of specific and comprehensive international policy frameworks and a number of legal

[213] "20. Overuse of pesticides has polluted water and soil, damaging the ecology of agriculture and creating hazards for human and animal health. […]. 36. Issue: Industrial development brings obvious benefits, but it frequently entails damage to the environment and to human health. The main negative impacts are: wasteful use and depletion of scarce natural resources; air, water and soil pollution; congestion, noise and squalor; accumulation of hazardous wastes […]. 41. With industrial growth and spread, the transport, storage and disposal of chemical, toxic and radioactive wastes will pose an increasingly serious challenge. …"

[214] "(69.) Emerging technologies offer the promise of higher productivity, increased efficiency, and decreased pollution, but many bring risks of new toxic chemicals and wastes […]. There is an urgent need for tighter controls over the export of hazardous industrial and agricultural chemicals. Present controls over the dumping of hazardous wastes should be tightened. […] (78.) The overriding policy objective must be to reduce the amount of waste generated and to transform an increasing amount into resources for use and reuse. This will reduce the volume that otherwise must be treated or disposed of through incineration, land disposal, or dumping at sea. […] (79.) The amount of wastes crossing national frontiers is increasing and is likely to continue to do so."

instruments that addressed the accelerating pollution- and waste-related issues. Specific manifestations of this are presented in the following sections, which demonstrate how far this process has come and how serious and multifaceted it has become. These and other large-scale human-induced perilous environmental affairs may seem like separate problems that need to be tackled on their own, but in fact, they are interconnected through their driving forces (root causes) and effects, likewise, in their relations with some other dangerous global environmental processes. For this reason, the respective comprehensive global policy frameworks are of paramount importance, which are concisely presented and evaluated in this chapter.

2.2. PERSISTENT ORGANIC POLLUTANTS

Numerous organic chemicals are very stable (persistent), so that when released into the environment, they remain there for a long time. More and more of these materials, produced by the chemical industry, have been used worldwide since the middle of the last century. This has become a global problem because such hazardous pollutants and wastes associated with these compounds may even reach areas very far from their source of origin and cause harmful effects.

2.2.1. Sources and effects of these pollutants

Persistent organic compounds (POCs) include pesticides such as DDT and other chemicals manufactured for use in various equipment, products, and production processes.

- These substances or their residues can enter the environment through their "emissions, discharges, and other losses" and continue their 'careers' as persistent organic pollutants (POPs). For example, when such pesticides are sprayed, pollution may inadvertently be caused if some part of them drifts away due to improper spraying equipment and procedures, and/or is carried away by air currents. While the aforementioned chemicals were produced (and some of them still are) for a specific purpose, other sorts of compounds (e.g., dioxins and furans) are generated as 'by-products' of industrial processes, solid fuel combustion, or during waste incineration and emitted into the environment. Since the 1960s, there has been increasing concern about these substances, and a growing number of studies have been published on their characteristics and the risks they pose [e.g., Brown et al., 1965; Gaines, 1969; Kelso et al., 1975[215]; Fiedler, 1993[216]; Ritter et al., 1995[217]; Gil & Sinfort, 2005].
- A great diversity of such substances are produced, including persistent, bioaccumulative, and toxic chemicals (PBT) and carcinogenic, mutagenic, and reprotoxic ones (CMR) [Darvas, 2006; Matthies et al., 2016]. In the framework of international environmental and health cooperation, obviously, the focus has been on those compounds whose problems affect many countries and which can exert harmful effects in various ways, even hundreds and thousands of kilometers from the place of their production or use and the source of their environmental release.

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[215] "The waste of pesticides at the time of application is a result of two major mechanisms: overapplication and nonuniform distribution. Loss of pesticides at the time of application are primarily the result of pesticides drift away from the target area […] and may pose both an immediate and long-term hazard to the surrounding environment." (pp. 4-5)

[216] "Since the first overview on formation and sources of polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) by US-EPA scientists was published in 1980 (Esposito et al. 1980), several updates are available in the international literature (DoE 1989, Fiedler et al. 1990, Rappe 1991, Hutzinger and Fiedler 1991). The findings can be summarized as follows (Hutzinger and Redler 1993): PCDD/PCDF have never been produced intentionally but occur as trace contaminants in a variety of industrial and thermal processes. Due to their chemical, physical and biological stability PCDD/PCDF are able to remain in the environment for long times." (p. 221)

[217] "[M]ost persistent organic pollutants originate almost entirely from anthropogenic sources associated largely with the manufacture, use and disposition of certain organic chemicals. In contrast, dioxins and furans are formed unintentionally in a wide range of manufacturing and combustion processes" (p. 24).

Exploring the harms and long-range transmission of persistent organic pollutants. There is a long history of use of chemical compounds of natural origin, and then synthetically produced ones against various pests[218] (e.g., arsenic compounds), the significant side effects of which were not or only barely taken into account [Jansen, 2000; Russel, 2001; Lipnick & Muir, 2001[219]].

- More than sixty years after the 19th-century synthesis of DDT, an organic chemical, its effectiveness as an insecticide, including against malaria-carrying mosquitoes, was discovered by Paul Müller in 1939. This scientific achievement was recognized with the Nobel Prize in Medicine in 1948.[220]
- This substance began to be produced and applied in ever-increasing quantities until the publication of Rachel Carson's book *Silent Spring* brought about a radical change in the way it was treated, due to the recognition of its unintended and widespread harmful environmental effects. "Since the mid-1940s over 200 basic chemicals have been created for use in killing insects, weeds, rodents, and other organisms described in the modern vernacular as 'pests' […] These sprays, dusts, and aerosols are now applied almost universally to farms, gardens, forests, and homes – nonselective chemicals that have the power to kill every insect, the 'good' and the 'bad', to still the song of birds […] Since DDT was released for civilian use, a process of escalation has been going on in which ever more toxic materials must be found." [Carson, 1962: p. 7] This led to a debate among experts who had different opinions about the 'benefits versus harms' relationship, but in the end, the application of this substance was first restricted and then banned in several countries.[221] The scientific discipline of ecotoxicology has specialized in researching such problems since the late 1960s onwards [Truhaut, 1975; Milinki, 2013].
- Other synthetic chemicals used in agriculture and industry, likewise pollutants (dioxins and furans) released unintentionally from various sources, often proved to be highly toxic, degrading very slowly in the environment and bioaccumulating in terrestrial and aquatic ecosystems. A striking example of their danger was provided by an industrial disaster in Italy in 1976, when dioxin gas released following an explosion at a chemical plant manufacturing pesticides near the Italian town of Seveso spread throughout a large area and caused serious health and environmental damage [Eskenazi et al., 2018].
- Most of these compounds emitted into the environment due to their persistence (low volatility) travel far and wide, and their presence has been detected almost everywhere on the planet, including in the polar regions and their wildlife [Moore, 1967[222]; Savoniva et al., 1995; Geisz, 2004]. The generation and management of waste containing these hazardous substances has also become a global problem [Atkins, 1972; Felsot et al., 2003[223]].
- After the seriousness of these processes became evident and technological solutions aimed at reducing the amount of organic pollutants already released into the environment did not lead to sufficient results, research, policies, and measures aimed at prevention became of decisive importance. Besides searching for alternative 'environmentally friendly' compounds and technologies, these activities were directed towards the elimination or at least reduction of the

[218] These are, in the broadest sense, the 'biocides'.

[219] "The history of persistent, bioaccumulative, and toxic chemicals (PBTs) is traced in this chapter from the 1825 synthesis of technical 'benzene hexachloride (BHC)' by Faraday to the current international efforts to phase out 12 'persistent, organic pollutants' (POPs) […] In the 1930s, new uses were sought for chlorine, leading to the discovery of a number of chlorinated insecticidal chemicals, including DDT". (p. 1)

[220] "… for his discovery of the high efficiency of DDT as a contact poison against several arthropods".

[221] The author of this book has also dealt with the DDT-related scientific process and international policymaking developments [Faragó, 2018].

[222] "So far organochlorine insecticide residues have been found in most of the specimens analysed […]; they have been recovered from plants in the Arctic, and from seals, penguins, skuas and fish from the Antarctic". (p. 23)

[223] "All countries have had to face problems of pesticide waste, although the nature of the problems and therefore the focus of attention are somewhat different between the highly industrialized countries and the developing countries. […] Regardless of a country's stage of development, literally every aspect of pesticide technology creates waste." (p. 124)

production, use, environmental release of and hazardous waste-generation associated with these chemicals [Lesage & Cretin, 2015]. In addition to the most frequently cited pesticides, the harmful effects of toxic polychlorinated biphenyls (PCBs) – the production of which began to increase from 1929 onwards and which were used, for example, in transformers, capacitors, and engine oils – also became a severe, global-level issue [Ritter et al., 1995].[224]

2.2.2. International science and policy cooperation

International expert cooperation facilitated the exploration of the intended and unintended effects of these pollutants, as well as the development and communication of the respective science-based recommendations.

- Since the 1960s, the FAO and the WHO, the specialized organizations of the United Nations in the field of agriculture and health, respectively, have been actively engaged in the identification of environmental and health hazards caused by the growing range of pesticides. They also agreed to support and co-organize joint meetings and assessment activities of the expert bodies working under their auspices[225] [FAO & WHO, 1965]. Moreover, WHO and WHO/IARC began issuing a series of publications about pesticides, and FAO also decided to compile and distribute informative booklets on the proper disposal of these substances.[226]
- Later, much more detailed analyses were conducted on the appropriate management options for all the persistent organic chemicals and their hazardous wastes within the framework of the International Programme on Chemical Safety (IPCS), launched with the participation of organizations dealing with health, occupational health, and environmental issues [WHO/IPCS, 1996]. It is worth mentioning that independently of the UN, these questions were also examined by the participants of the Toxicology Forum, which was set up in 1976.[227]
- After the 1992 UN Conference on Environment and Development, the cooperation on this matter was further expanded with the establishment of the Intergovernmental Forum on Chemical Safety (IFCS) and the collaboration of even more specialized institutions that participated in the Inter-Organization Programme for the Sound Management of Chemicals (IOMC). At that time, in view of international recommendations, several countries banned the production and use of some of the aforementioned pesticides and regulated the fate of the remaining stocks and their waste.
- This topic received significant attention in the organization formed in 1996 by the countries 'bordering' the Arctic,[228] in the joint environmental protection program of the three North American states since 1994,[229] and within the OECD since the late 1990s.[230] EU Member States

[224] "The properties of unusual persistence, when coupled with other characteristics such as semi-volatility, have resulted in the presence of compounds such as PCBs all over the world, even in regions where they have never been used." "PCBs have been manufactured since 1929, first by Monsanto Chemical Corporation in the USA, and were used widely in transformer and capacitor oils […]. From the early 1970s to the mid-1980s, the use of PCBs was progressively restricted to closed electrical systems, where they remain in use throughout most of the world." (pp. 1, 93)

[225] FAO Panel of Experts on Pesticide Residues in Food and the Environment; WHO Expert Group on Pesticide Residues.

[226] WHO: Pesticide Residues Series, Environmental Health Criteria; WHO/IARC (International Agency for Research on Cancer): Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. FAO: Pesticide Disposal Series.

[227] Árpád Somogyi played an active role in the Toxicology Forum and was later the initiator of the establishment of the European Food Safety Authority.

[228] Arctic Council Action Plan to Eliminate Pollution of the Arctic.

[229] North American Agreement on Environmental Cooperation: "Sound Management of Chemicals" initiative, 1997

[230] OECD: Harmonised integrated classification system for human health and environmental hazards of chemical substances, 2001.

first introduced community regulations for some pesticides (e.g., DDT), then for persistent organic pollutants in general and their hazardous waste.[231]

For the development of global policy programs, there was more than enough scientific and professional knowledge, and science-based recommendations in the second half of the 1980s, regarding the dangerous effects of these substances. As formerly mentioned, the global political atmosphere became more favorable, which was also an essential condition for broadening and increasing fruitful international policy cooperation on environmental issues.

- With the rapid expansion of the production, distribution, and use of pesticides, the health and environmental risks, the emissions of pollution, and the generation of hazardous waste from these chemicals have greatly increased. The WHO Assembly resolved in 1975 to establish the *Recommended Classification of Pesticides by Hazard* (which was later regularly updated and supplemented) and proposed its application by Member States, international agencies, and regional bodies [WHO, 1975]. Also, in order to mitigate these risks, FAO introduced the *International Code of Conduct on the Distribution and Use of Pesticides* in 1985, which also included recommendations for the disposal of unused pesticides, their containers, and packaging to be treated as hazardous waste [FAO, 1985]. This code has also been amended and supplemented several times since then.

- In the UN programs on sustainable development approved between 1992 and 2015, the chemical and waste management goals and provisions obviously were relevant to the persistent organic pollutants, too. The 1992 program (*Agenda 21*) specifically highlighted the importance of the proper disposal or treatment of such substances: "Governments should intensify research and development activities on cost-effective alternatives for processes and substances that currently result in the generation of hazardous wastes that pose particular problems for environmentally sound disposal or treatment, the possibility of ultimate phase-out of those substances that present an unreasonable or otherwise unmanageable risk and are toxic, persistent and bio-accumulative to be considered as soon as practicable." [UN, 1992: 20.13(c)][232]

- Discussions also began in UNEP forums on the need for global regulation of pollution; in particular, a global action program was prepared on land-based activities that damage the marine environment [UNEP/GPA-LbA, 1995], which also addressed persistent organic pollutants, including wastes containing them and emissions from waste incineration.[233]

The need for a global POP convention was raised and then accepted shortly after the 1992 UN conference [UNEP, 1995]. Just then, the development of a POP protocol to the 1979 UNECE convention on transboundary air pollution (CLRTAP) was underway, but it became obvious that only a global legal mechanism could facilitate the prevention of the expanding and intensifying transboundary harms of such pollutants all over the world.

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[231] 79/117/EEC prohibiting the placing on the market and use of plant protection products containing certain active substances (1978); Regulation (EC) No 850/2004 of the European Parliament and of the Council of 29 April 2004 on persistent organic pollutants and amending Directive 79/117/EEC (replaced by Regulation (EU) 2019/1021).

[232] (14.74) "Integrated pest management should go hand in hand with appropriate pesticide management to allow for pesticide regulation and control, including trade, and for the safe handling and disposal of pesticides, particularly those that are toxic and persistent." (19.21(a)) "Strengthening research on safe/safer alternatives to toxic chemicals that pose an unreasonable and otherwise unmanageable risk to the environment or human health and to those that are toxic, persistent and bio-accumulative and that cannot be adequately controlled."

[233] "103 (a) To reduce and/or eliminate emissions and discharges of POPs that threaten to accumulate to dangerous levels in the marine and coastal environment; […] (c) To use cleaner production processes, including best available techniques, to reduce and/or eliminate hazardous by-products associated with production, incineration and combustion […]; 143. Uncontrolled burning of litter containing plastics may generate significant quantities of POPs, metals and hydrocarbons which can reach the marine and coastal environment."

- First, global regulation targeted the pollutants that were taken into account when designing the pan-European protocol referred to above.[234] These substances included dioxins, furans, and PCBs, while all the others were pesticides, the waste and environmental emissions of which were also covered by the provisions of this new legal act.
- At the pan-European level, four more chemicals were finally controlled [CLRTAP/POP, 1998][235] and the relevant provisions required (i) a ban or temporary restriction on their utilization, (ii) the disposal of remaining and no longer usable stockpiles in accordance with the general regulations applicable to hazardous wastes, and (iii) the stipulation of some limit values for emissions from waste incineration (i.e., for dioxins and furans). The range of such substances was later expanded. Furthermore, the previous regulations and emission limits were tightened.
- The *Stockholm Convention on Persistent Organic Pollutants*, completed and adopted in 2001, followed the concept of the pan-European protocol, but its scope only comprised the 12 chemicals initially included in the preparatory process of the latter [SC, 2001]. The convention also deals with the treatment of their hazardous wastes,[236] as well as the unintentional atmospheric emissions of such pollutants. The substances are grouped into three categories and listed in the respective annexes: (A) pesticides and some industrial POPs to be 'eliminated', i.e., for which measures were defined for the prohibition/elimination of their production and use; (B) chemicals whose production and use were to be restricted (primarily, DDT and some industrial POPs added later to this list, and (C) those formed and released unintentionally, for which a list of measures were defined "to reduce the total releases derived from anthropogenic sources […] with the goal of their continuing minimization and, where feasible, ultimate elimination".[237] (Some specific exemptions could be requested by Parties for a limited period under the provisions concerning, for instance, the production and/or use of the controlled chemicals.)
- The range of substances was expanded by amendments of the abovementioned annexes so that there are already more than thirty types of chemicals slated for elimination or restriction, including more pesticides and perhaps the most frequently referred to and criticized fluorinated compounds, the PFAS[238] (which are informally called 'forever chemicals' because of their extremely persistent nature). The latter substances began to be widely used from the 1950s onwards, and in view of the increasing awareness of their especially harmful influence on human health and the environment, at least some of the most critical representatives of these chemicals were added to the *Convention*'s annexes for restriction and/or elimination.
- The international transportation of hazardous wastes is discussed in some detail below (Section 2.3), therefore, it is only mentioned here that the scope of the *Basel Convention* on the transboundary movement of hazardous wastes also extends to persistent organic compounds and

[234] These substances were as follows: the same pesticides that later were included in Annex A and Annex B of the global convention (see below), moreover, the dioxins, furans and PCBs. Eventually, the protocol also covered the following POPs: chlordecone, hexabromobiphenyl, HCH (hexachlorocyclohexane), and PAHs (polycyclic aromatic hydrocarbons).

[235] As a member of the Hungarian delegation, the author of this book was present at the Pan-European environmental conference held in Aarhus (Denmark) in 1998, where this POP-protocol was finalized and opened for signature.

[236] (Art.6) "… wastes, including products and articles upon becoming wastes, consisting of, containing or contaminated with a chemical listed in Annex A, B or C, are managed in a manner protective of human health and the environment, each Party shall: […] Take appropriate measures so that such wastes, including products and articles upon becoming wastes […] Disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed".

[237] Annex A: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene; Annex B: DDT; Annex C: dioxins, furans, polychlorinated biphenyls (PCB) and hexachlorobenzene (because it is unintentionally produced and emitted besides having been produced and used as a fungicide).

[238] PFAS: per- and polyfluorinated alkyl substances.

wastes containing them, in particular, pesticide wastes [BC, 1989: Annex VIII, List A, A4030[239]; PCBs, furans and dioxins: A3180, A4110].

2.2.3. Monitoring the implementation and the assessment of the effectiveness of the international response policies

Controversy arose because while these chemicals have proven effective for agricultural, industrial, and other purposes, once released into the environment, they have serious impacts as pollutants and hazardous waste. For this reason, within the framework of international cooperation, the regulation of the production, use, and environmental releases of these substances (including the respective targets and obligations) was gradually tightened and also regularly assessed for effectiveness, besides monitoring and enforcing compliance with them.

- Almost all UN Member States became Parties to the 2001 *Stockholm Convention* (but notably, e.g., the USA did not, although the production and use of the pesticides concerned were banned there; further, the USA and the Russian Federation are not Parties to the pan-European POP protocol, in addition to a few more European countries).
- Some countries continued to produce and export pesticides (e.g., aldrin, lindane) and other chemicals referred to in the *Convention* and its amendments (at least based on information from national reports submitted by 2022) [UNEP/POP, 2023a: pp. 52-53]. As concerns DDT, it was probably produced only in one country (India) and used in a few others [WHO/IARC, 2019; UNEP/POP, 2021; UNEP/POP, 2023a].[240]
- Traces of these substances can still be identified in areas even far from their previous emission sources. In this regard, one noteworthy example is that – although the use of DDT, the 'most notorious' pesticide, continued to decline,[241] its deleterious effect is still detectable in Antarctic biota. Findings quoted from the studies below clearly demonstrate how far-reaching and long-term the environmental implications of such chemicals have been. (i) "POPs reach polar regions by long-range atmospheric transport. […] p,p'-DDE, a derivative of DDT, appears to have declined in Adélie penguin livers from 1964-1992 with a half-life of ≈6 years, but p,p'-DDE levels in the fat of these animals increased over the same time period." [Geisz, 2004] (ii) "The results obtained suggest long-range transport as the main source of the analyzed POPs in both penguin species. […] Despite their prohibition and regulation on a global scale, chemical contamination by POPs persists and continues to reach remote regions such as Antarctica." [Morales et al., 2022] (iii) "DDT was in general decreasing in all reported media and regions; however, the levels were increasing in Antarctic biota. The pattern of DDT was changing, with an increasing ratio of the metabolite DDE compared to its precursor DDT, which could be an indication of the lack of new 'fresh' DDT." [UNEP/POP, 2023b: p. 97]

[239] "A4030: Wastes from the production, formulation and use of biocides and phytopharmaceuticals, including waste pesticides and herbicides which are off-specification, outdated, or unfit for their originally intended use".

[240] "7 companies in the USA in 2016 reported production of aldrin and/or dieldrin" [WHO/IARC, 2019: p. 195]. "(11.) It is most likely that India is currently still the only producer of DDT. Contemporary data on production amounts by India are not available but, nonetheless, it is safe to assume that production amounts have correlated to the use amounts, which have shown a declining trend in previous years" [UNEP/POP, 2021]. "(164.) Export of DDT was reported only by India. […] In the period 2018-2020, DDT was exported to Botswana, Namibia, South Africa, Zambia and Zimbabwe" [UNEP/POP, 2023a].

[241] "Since the first effectiveness evaluation the pace of decline in the use of DDT, and therefore the associated manufacture, imports and exports has continued, with a 60% reduction in use between 2014 and 2020. The number of Parties indicating they have adopted measures to control DDT continues to increase slightly from 70% in the first effectiveness evaluation to 80%." [UNEP/POP/DDT, 2023b]

- The safe disposal of waste and residues of pesticides controlled by the *Convention* remained unresolved in many developing countries.[242] This problem is especially valid for DDT [UNEP/POP, 2021].[243]
- Nevertheless, overall, the referenced international provisions and national measures taken on their basis have contributed to reducing the production, use, and harmful effects of at least the initially controlled chemicals under POP agreements. However, monitoring and evaluating the effectiveness of global regulatory provisions and their enforcement in the case of "newly listed" persistent organic pollutants indicates a much more 'mixed' – i.e., less positive – picture [UNEP/POP, 2023b].[244]

* * *

Much more scientific knowledge is available about persistent organic chemicals, environmental releases, and the long-range transmission of associated pollutants, as well as the resulting harmful health and environmental effects. Nevertheless, further, more thorough studies and more stringent measures are still necessary. Otherwise, this dangerous problem will remain with us for a very long time. It is especially instructive what the editors of a recent publication noted on this matter: "From the monitoring data, it can be concluded that the stopping of production and use of POCs did not result in an immediate reduction of POPs in the environment […]. The worldwide emerging PFAS contamination shows that authorities have learned very little from the environmental and health problems DDT, PCB, and dioxins caused in the 1960s–1990s" [Fiedler et al., 2023].

[242] "Two-thirds of responding countries lack guidance on safe disposal of agricultural pesticide waste or empty containers, and half of the countries lack a system to collect empty pesticide containers." [WHO & FAO, 2019: p. viii] "Half a million tonnes of obsolete pesticides are scattered throughout the developing world. […] The FAO Programme on Prevention and Disposal of Obsolete Pesticides has developed an extensive training programme, published guidelines and other resources for countries to effectively and safely conduct the necessary activities to dispose of stockpiles and implement specific measures to avoid their re-accumulation." [SAICM, 2020: p. 39]

[243] "(14.) The estimated global total of reported DDT obsolete stockpiles ranged from a low estimation of 5,000 Metric Tonnes (MT) to a high estimation of 46,000 MT. Not included in these numbers were amounts of materials and equipment contaminated with DDT (e.g., soil, store structures) that were expected to constitute a larger volume than the stockpiles themselves […]. As the main obstacle for environmentally sound disposal of DDT, the report identified the absence of a waste management industry in many parts of the world." "(117.) Substantial project efforts are ongoing in selected countries to dispose of large quantities of obsolete DDT and associated waste."

[244] "In general, concentrations are declining and are starting to level off where regulatory action was taken decades ago. […] The patterns for chemicals listed since 2009 are complex and variable across chemicals, media and areas. For example, certain chemicals showed mostly declining or no change in trends, while others showed increasing trends followed by decreasing trends, or consistent decreasing trends depending on the location. […] There are insufficient data to detect trends for many of the newly listed POPs." (p. 13)

2.3. TRANSBOUNDARY MOVEMENT OF HAZARDOUS SUBSTANCES AND INTERNATIONAL TRADE IN CHEMICALS AND EMISSIONS ALLOWANCES

As the amount of waste, including hazardous waste, has increased rapidly in developed countries since the middle of the last century, one way to get rid of it has become to transport some of it to an area under the jurisdiction of another country, with or without prior bilateral consent between the exporter and importer. This has occurred due to improving environmental awareness in developed countries, concerns about the harmful effects of hazardous waste, the strengthening national regulations, and the resulting higher costs of waste management. The most controversial and conflict-provoking issue became the transboundary carriages of not only wastes but generally the trade and transport of various types of hazardous substances. Therefore, international regulations have been elaborated to control or even restrict/ban such operations. International mechanisms were also established concerning atmospheric pollutants, with rules for trading with their emission units in the framework of some environmental agreements.

2.3.1. A 'simple' way to get rid of waste?

The underlying motives for transporting waste from a developed country to another country are rather obvious [Hackmann, 1994[245]; Kerényi, 1995[246]] and include the NIMBY argument in a broader sense, i.e., objections raised by residents of a town, region or country: "Waste generators in many industrialized States are faced with an increasing scarcity of disposal facilities, growing public opposition to the establishment and operation of such facilities based on the so-called NIMBY (Not In My Back Yard) syndrome, a tightening of environmental rules and standards, and escalating disposal costs as a result of these developments. […] The typical target country may offer disposal options at prices that are often a mere fraction of the disposal costs in the country of origin". [Kummer, 1994]. The opposition to such controversial waste 'management/disposal' procedures has strengthened since the late 1980s.

- The members of a high-level commission established in 1983 by the UN General Assembly also examined this issue. According to their assessment, "78. The amount of wastes crossing national frontiers is increasing and is likely to continue to do so. Between 1962 and 1983, wastes transported in Western Europe for disposal in another country virtually doubled, reaching some 250,000-425,000 tons […]. This increase may be attributed partly to the availability of relatively low-cost, legal, land-based disposal facilities in some countries" [WCED, 1987]. Civil society organizations have also done much to uncover hazardous waste shipments to less developed countries for dumping or 'recycling': "[W]aste traders have attempted to ship more than 163,000,000 tons of wastes around the world since 1986. Of this total, approximately 10,000,000 tons of toxic waste have actually been exported from the countries of origin, often ending in the less industrialized countries that do not have environmentally sound facilities to manage the waste" [Vallette & Spalding, 1990].
- Indirectly, such consequences have been caused by the relocation ('offshoring') of pollution-intensive industrial activities to other countries. One of the controversial examples of such 'pollution offshoring' is the series of plants operating in the northern border region of Mexico, most of which were owned by US companies. Despite the agreement between the two countries,

[245] "Despite the negative attitudes towards waste exportation, it has taken place in the past and will continue to take place in the future. It holds true that the more individual countries raise their environmental standards or tighten their disposal regulations, the more incentive there is for exports. Waste exports are a means of avoiding domestic standards". (p. 293)

[246] "Regional differences […] in the production of hazardous waste and differences in countries' environmental legislation have led to large-scale waste exports in recent decades. Countries exporting toxic waste find it more economically advantageous to transport than dispose it." (p. 234)

a significant part of the hazardous waste generated during production remained in Mexico [Sanchez, 1990].[247]

- Both types of 'solutions' – exporting hazardous waste or offshoring heavily polluting production from a developed country – have affected many countries in Asia, Africa, Latin America, and Eastern Europe.

The proliferation of incidents involving the North-South 'waste trade' associated with serious health and environmental implications has caused growing concern. The following two affairs attracted outstanding attention worldwide.

- It is estimated that in the mid-1980s, there was sufficient national capacity to properly treat only about a fifth of Italy's hazardous waste. For this reason, some of the unprocessed waste 'set out on a journey': first in 1987, then in 1988, it was shipped to a Nigerian settlement (Koko), until the sharp diplomatic conflict between the two countries ended with this waste being returned to its country of origin [Akingbade, 1991; Lipman, 2002[248]]. Another example is that only part of the hazardous waste transported from a US port in 1986 could be unloaded in Haiti (near Gonaïves), while the rest was dumped at sea [Vu, 1994].
- Such waste shipments also occurred within Europe, including illegal 'West-East' ones, and those between Western European countries. Of the latter, the 'Seveso affair' is particularly noteworthy. This occurred after a chemical disaster in the northern Italian town in 1976. The large amount of hazardous waste generated at that time was placed in barrels destined for disposal 'somewhere'. After some time, these barrels were found in a French village (Anguilcourt) in 1982 and then incinerated in Basel [Lagadec, 1984[249]; Vesseron, 1990].
- These incidents contributed to developed countries beginning to regulate the transboundary movement of hazardous waste (see below), and also had a catalyzing role in the launch of international negotiations that began in 1987, leading eventually to the adoption of the *Basel Convention* in 1989.[250]

The beginnings of international waste movement regulatory cooperation can be dated back to the early 1980s. During this process, significant differences in the situations of the respective countries had to be bridged.

- Representatives of developing countries urged the global regulation of the transboundary movement of wastes, as most of the relevant government and non-government representatives wanted to avoid remaining in the 'humiliating' role of receiving/importing other people's hazardous waste (regardless of any real or false pretext).
- One of the first outcomes of the international negotiations that began in 1982 was the preparation of the non-binding *Cairo Guidelines and Principles for the Environmentally Sound Management of Hazardous Wastes*, which were finalized in 1985 and officially approved in 1987 by the Governing Council of the UNEP. One part of this document was devoted to the transfrontier

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[247] "The empirical data available suggest the generation of a considerable volume of hazardous waste by the maquiladoras. The data also suggest the illegal disposal or treatment of this waste in Mexico […]. According to the agreement, the maquiladora must return its waste generated in Mexico back to the United States. […] However, as of 1989 few effective improvements have been achieved". (p. 168)

[248] "Several thousand tons of highly toxic and radioactive waste, labeled 'substances relating to the building trade' were exported from Italy to Koko, Nigeria, and stored in drums in a backyard. Many of these drums were damaged and leaking; workers packing the drums into containers for retransport to Italy suffered severe chemical burns and partial paralysis …". (p. 67)

[249] "Les déchets de Seveso sont-ils en France?" (p. 25)

[250] It is also worth mentioning the case when in 2006, several thousand tons of 'mixed' waste illegally arrived from two German provinces to several Hungarian settlements. Referring to international and EU regulations, the Hungarian side demanded the return of the entire shipment: following four years of negotiations, this was at least partially achieved. The author of this book participated in this negotiation process and gained direct experience of how difficult it was to enforce even commonly agreed-upon regulations.

movements of such wastes. The respective requirements included, among other things, (i) the notification and consent procedures (i.e., providing full information on the waste to be moved/transported by the exporter State to the importing and any transit State(s), and furthermore, initiating that transaction only if the State of import and transit State(s) have given their consent to that movement), (ii) the "sovereign right of a State to refuse to accept within its territory hazardous wastes originating elsewhere" and (iii) even the re-admittance of the waste by the State of export if that movement occurred despite being opposed by the State of import or transit State(s) [UNEP, 1987b: Part VI. pars. 26, 27].

- In the meantime, developed countries formulated their first regulations on this matter, which closely conformed to those provisions embedded in the final version of the aforementioned international guidelines. According to the decision by the Council of the OECD on *Transfrontier Movements of Hazardous Waste*, its member countries shall control such transactions, inter alia, by (i) following the notification and consent procedures, (ii) desisting from a projected transfrontier movement if this is opposed by the countries concerned and (iii) reimporting the waste if it is shipped against the decision of the importing or a transit country [OECD, 1984: pars. 5.1, 8, 9]. The same year, the members of the European Economic Community adopted a similar legal instrument entitled *Transfrontier Movements of Hazardous Waste* [EEC, 1984].
- Since all this seemed insufficient to alleviate 'North-South conflicts' about waste shipments (especially on the part of African countries), a decision was made in 1987 to develop a global convention to control these transactions, the first negotiation round of which was held in Budapest.[251]

Besides waste-related international affairs, trading in general with hazardous substances (chemicals and pesticides) also raised concerns because of their harmful impacts on human health and the environment. The provisions for these procedures were prepared in parallel to the above-mentioned *Cairo Guidelines*, but this time, they were not about waste export-import operations.

- The *London Guidelines for the Exchange of Information on Chemicals in International Trade* were adopted in 1987 by the Governing Council of UNEP (at the same meeting where the guidelines on waste shipments were approved). As hazardous waste movements were controlled by the *Cairo Guidelines*, they were excluded from the scope of these *London Guidelines*, and besides them, e.g., pharmaceuticals and radioactive materials were also not under their scope. Some of the key components of this international instrument are as follows: (i) the definition of chemicals (including pesticides) and their categories for which all uses were banned or severely restricted in a (developing)[252] country and which should not be exported without the explicit consent of that country; (ii) the application of the International Register of Potentially Toxic Chemicals (IRPTC) as the 'data bank' of these trading operations[253]; (iii) the inclusion of the 'prior informed consent' (PIC) procedure in these guidelines (which occurred two years later with an amendment to the initial version of this document) [UNEP/IRPTC, 1989; UNEP, 1989: pars. 1.a, b, c, h and par. 6].
- As the most essential criterion applicable to these transboundary movements, it is worth quoting here the meaning of prior informed consent (PIC) and the respective procedure: (i) PIC "refers to the principle that international shipment of a chemical that is banned or severely restricted in order

[251] UNEP Governing Council (17 June 1987) Decision 14/30: Environmentally sound management of hazardous wastes.

[252] "Although the Guidelines have not been prepared specifically to address the situation of developing countries, they nevertheless provide a framework for the establishment of procedures for the effective use of information on chemicals in these countries. Implementation of the Guidelines should thus help them to avoid serious and costly health and environmental problems due to ignorance about the risks associated with the use of chemicals, particularly those that have been banned or severely restricted in other States." [UNEP, 1989: Introduction, par. 8]

[253] The IRPTC was established in 1976 and has been systematically updated since then. It also served for registering and disseminating information submitted by the potential importing countries concerning the permission or refusal of use and importation of specific chemicals.

to protect human health or the environment should not proceed without the agreement, where such agreement exists, or contrary to the decision, of the designated national authority in the importing country" and (ii) the PIC procedure "means the procedure for formally obtaining and disseminating the decisions of importing countries as to whether they wish to receive future shipments of chemicals which have been banned or severely restricted" [UNEP, 1989: pars. 1.g, 1.h].

- Besides agreeing on the above guidelines and enlarging the role of the chemicals register (IRPTC), the UNEP emphasized the need to make further international efforts to address these hazards: "There is a growing awareness of the hazards associated with trade in chemicals, pesticides and some other products, but international practices for controlling the transport of hazardous chemical goods do not yet provide for a systematic consideration of the environment." [UNEP, 1987a: par. 64] In line with that 'warning', the need for another international system of information (besides IRPTC) emerged in the late 1980s, the development of which was endorsed by the 1992 UN conference (UNCED) [UN, 1992: UN, 19.27].[254]
- The *Globally Harmonized System of Classification and Labelling of Chemicals* (GHS) was adopted about a decade later, first by the UN Committee of Experts on the Transport of Dangerous Goods and then endorsed by the UN Economic and Social Council [UN/ECOSOC, 2003]. Among the precautionary warnings and corresponding pictograms listed in the GHS, those that refer to environmentally hazardous substances are primarily related to the topics discussed in this chapter (A.2.27-28, A.3.4).

2.3.2. International conventions on the transboundary movements of and trade in hazardous substances

Due to significant differences in positions and conflicts of interest, it was difficult to reach a consensus on regulating the international movement of hazardous wastes, which was ultimately achieved only after accepting substantial compromises. While some developing countries insisted on banning entirely the export of such waste to their territories, developed countries considered its export for recycling to be beneficial for both economic and environmental reasons. The conditions of transportation were also deemed important, as the unsafe delivery of hazardous substances could cause serious damage to a country of transit and the receiving country.[255]

- *The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal* imposed strict conditions on the export of such wastes to other countries [BC, 1989].
- Under the general obligations of this legal instrument, it is essential (i) to prevent the generation of such wastes, but if these are nevertheless produced, then to treat them in an environmentally sound manner, and (ii) to adhere to the stringent rules for their transboundary movement. Therefore, each Party shall ensure (i) "the generation of hazardous wastes and other wastes within it is reduced to a minimum" and "the transboundary movement of hazardous wastes and other wastes is reduced to the minimum" (pars. 2.a, 2.d), furthermore, "the availability of adequate disposal facilities, for the environmentally sound management of hazardous wastes and other wastes […] be located, to the extent possible, within it" (par. 2.b). As regards transboundary movements, i.e., (ii) the exporting and importing provisions, only two basic obligations are highlighted here: "Parties exercising their right to prohibit the import of hazardous wastes or other wastes for disposal shall inform the other Parties of their decision …" (par. 1.a) and "Parties shall

[254] (19.27) "A globally harmonized hazard classification and compatible labelling system, including material safety data sheets and easily understandable symbols, should be available, if feasible, by the year 2000."

[255] Such pollution can also occur if the hazardous waste shipment occurs via an 'international area', i.e., a maritime area beyond national jurisdiction. (This topic is considered in the next subsection.)

prohibit or shall not permit the export of hazardous wastes and other wastes to the Parties which have prohibited the import of such wastes …" (par. 1.b). The *Convention* also provided a long list of controlled waste categories.

- Some of the crucial compromises were that (i) hazardous waste transactions with non-Parties were forbidden – i.e., exports to or imports from them (par. 4.5), (ii) illegal waste trafficking to be considered a criminal act (par. 5.3) and (iii) the stipulation of a total or at least partial ban on these waste shipments should be examined three years after entry into force of the *Convention*.[256] This topic also arose at the 1992 UN conference on sustainable development, where developing countries urged the tightening of the *Basel Convention* (which was already in force at that time) with the banning/prohibiting of exporting hazardous wastes under certain circumstances [UN, 1992].[257]
- A complete ban was mandated in the *Lomé IV Convention* concluded in 1989 between an organization of developing countries (OACPS)[258] and the European Community, and then in the *Bamako Convention* adopted by African countries in 1991. Eventually, the 1995 amendment of the *Basel Convention*, informally called the *Basel Ban*, prohibited for the developed countries – i.e., members of the OECD and the European Community – the transfer of hazardous wastes to developing countries for any purpose after 1997 [BC/BBA, 1995]. Since then, the Parties have not only further tightened the *Convention* at several other points (e.g., expanding the scope of hazardous wastes), but also supplemented it in 1999 with a protocol, in consonance with which the Party causing the damage resulting from the transboundary movement and disposal of hazardous waste is liable to provide financial compensation [BC/PLC, 1999]. In 2019, plastic waste was added to the list of hazardous wastes (with some exceptions) [UNEP/CHW, 2019].[259]

The international trade in hazardous chemicals was also on the agenda of the 1992 UN conference (UNCED), and in its outcome document, the need for a legally binding instrument for controlling these trading affairs was clearly stated [UN, 1992].[260]

- The elaboration of legally binding rules for the international trade in hazardous chemicals started after 1995 in collaboration of UNEP and FAO. Eventually, the *Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade* was adopted in 1998.
- In line with its objective, shared responsibility and cooperative efforts among Parties are promoted in respect of the international trade of hazardous chemicals to protect human health and the environment. With this aim, the Parties shall (i) facilitate information exchange on the characteristics of such chemicals, (ii) develop their national decision-making processes

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[256] "15.7. The Conference of the Parties shall undertake three years after the entry into force of this Convention […] if deemed necessary, to consider the adoption of a complete or partial ban of transboundary movements of hazardous wastes and other wastes in light of the latest scientific, environmental, technical and economic information."

[257] Chapter 20. Environmentally sound management of hazardous wastes, including prevention of illegal international traffic in hazardous wastes. 20.33. The objective of this program area is: "To adopt a ban on or prohibit, as appropriate, the export of hazardous wastes to countries that do not have the capacity to deal with those wastes in an environmentally sound way or that have banned the import of such wastes". (The author of this book participated in the negotiations on the finalization of this document at the 1992 UN conference as a member of the Hungarian delegation, where achieving consensus on the chapter on hazardous wastes was also only possible after lengthy debates and agreeing on numerous compromises.)

[258] OACPS: Organisation of African, Caribbean and Pacific States.

[259] Decision BC-14/12: Amendments to Annexes II, VIII and IX to the Basel Convention.

[260] (19.38.b, 19.39.d) "To achieve by the year 2000, as feasible, full participation in and implementation of the PIC procedure, including possible mandatory applications through legally binding instruments contained in the Amended London Guidelines and in the FAO International Code of Conduct, taking into account the experience gained within the PIC procedure. […] Implement the PIC procedures as soon as possible and, in the light of experience gained, invite relevant international organizations, such as UNEP, GATT, FAO, WHO and others, in their respective area of competence to consider working expeditiously towards the conclusion of legally binding instruments."

concerning the import and export conditions of these substances, and (iii) disseminate these decisions to all other Parties [RC, 1998: Art. 1].

- In formulating its numerous provisions, the relevant passages of the *London Guidelines* were taken into account, including the definitions, exemptions, and basic elements of the PIC procedure. However, the scope of the *Convention* was much more extensive and comprised very detailed obligations for the Parties concerning procedures related to banned or severely restricted chemicals (Art. 5), hazardous pesticide formulations (Art. 6), and the imports and exports of controlled chemicals (Art. 10-13, Annex III, Annex V). (Similarly to the *Guidelines*, the *Convention* was not applicable, for example, to hazardous wastes, the trading affairs of which were controlled by the *Basel Convention*.)

2.3.3. Is the illegal transboundary movement of and trade in hazardous substances declining?

The adequacy of the legally binding international regulation of the movement of hazardous wastes across national borders can be assessed based on how 'ambitious' its provisions are, how broad the range of its Parties is, and how effective its implementation is. The activities of the respective international organizations (UNEP, OECD, OACPS) and the adherence to the relevant non-binding instrument, the *Cairo Guidelines*, by the States play an important role in curbing illegal trades, but the most significant factor in this context is the *Basel Convention*, which has been supplemented, amended and tightened several times since 1989.

- This *Convention* has achieved near-universal acceptance, but it should be noted that (for clearly understandable reasons) quite a few developing countries decided to accede to it only after the adoption of the 1995 *Basel Ban*. (It also took several years for the British and Spanish sides to agree on the application of the specific provisions to Gibraltar.) The US signed the *Convention* but did not ratify it, nor did Haiti (which is particularly worrying in light of the incident that occurred in 1986, as mentioned above).
- Almost a quarter of a century passed before the *Basel Ban* came into force, and only about a hundred States have assumed this legal obligation, which completely bans for the developed countries the international transport of hazardous waste. (It is noteworthy that Australia, Canada, Japan, New Zealand, Russia, and the USA are not part of this group, i.e., have remained non-Parties.)
- The fate of the 1999 *Liability Protocol* seems 'hopeless', as only a few developing countries have acceded to it, even though numerous damages caused by hazardous wastes shipped from developed countries have become generally known since its adoption.[261]

The *Rotterdam Convention* (1998) entered into force in 2004 and proved less effective at least in legal terms, than the *Basel Convention*.

- Many countries became Parties to this *Convention* only after it was enforced (and some others did even later, like Indonesia in 2013, the Russian Federation in 2011, and Turkey in 2017), and quite a number of UN Member States still have not acceded to this important treaty (including the USA).
- Besides disagreements between the Parties regarding the inclusion of some further chemicals (especially, pesticides) in the list of controlled substances, one of the most problematic parts of

[261] Despite the existence of global and European regulations, 'mixed' municipal and industrial hazardous wastes also arrived in Hungary from other European countries, and the author of this book was involved in some stages of these dispute settlement processes. These occurrences were as follows: wastewater from Romanian mines containing particularly hazardous chemicals that polluted the Tisza River (2000), industrial wastewater from tanneries (leather factories) discharged to the Rába River (2007), and the above-mentioned illegal transport of containers containing 'mixed' waste from Germany (2007).

the *Convention* for many Parties and perhaps for some of 'non-Parties' was probably the dispute settlement procedure and/or 'only' its interpretation (Art. 20, Annex 6). These and other issues (e.g., compliance) considerably limited the effectiveness of the *Convention* and were repeatedly discussed by the Conference of the Parties and its relevant bodies (Chemical Review Committee, Compliance Committee).

- An extensive analysis published by UNEP also revealed that the lack of clarity in some of the definitions and provisions of the above-mentioned legal instruments is one of the reasons for their ineffective implementation and enforcement [UNEP, 2020: p. 57].

The illegal transboundary traffic of and international trade in hazardous/dangerous substances after the approval of the respective guidelines and conventions. The cases ('abuses') and studies cited below unfortunately and clearly indicate that international regulations alone do not sufficiently guarantee the effective management of these perilous issues.

- Shortly after the *Basel Convention* was adopted in 1989, toxic waste was shipped from the USA to Bangladesh in 1992 [Clapp, 1997][262]; the disclosure of this contributed to the finalization of the text and approval of the *Basel Ban* in 1995.
- A large amount of coker naphtha (petroleum coke) was purchased in Mexico by the then Dutch-based company Trafigura, and these cargos were then uploaded to a Greek-owned tanker (registered in Panama) in early 2006. The treatment of this substance ('desulfurization' by caustic washing) occurred in various locations, including onboard the tanker. Several attempts were made to offload the hazardous waste from these washing operations, for instance, in the port of Amsterdam, but all these attempts failed. The tanker continued its journey towards several African ports, but finally, its cargo was offloaded and dumped in Côte d'Ivoire, causing severe health problems to tens of thousands of people on the island. A large part of this toxic waste was removed, shipped to France, and incinerated there [EP, 2006; Greenpeace & Amnesty Int'l, 2012; Sirleaf, 2019].
- Two Brazilian ports received 110 containers of hazardous waste from the United Kingdom in 2008-2009. Following legal proceedings, the 'sender' had to return and dispose of most of this waste [Rucevska et al., 2015].[263]
- With all three 'ominous' occasions described above, the developed country exporters of the waste initially denied their responsibility – however, their countries' positions regarding the *Basel Convention* differed. The USA has not become a Party to it since then, while the Netherlands and the UK have become participants not only in the *Convention*–related collaboration but have also undertaken the obligations stemming from its amendment, i.e., the *Basel Ban*.
- Overall, the global volume of hazardous waste is increasing, and with it, an extensive international 'waste market' continues to operate [Rucevska et al., 2015].[264] The Chinese import restrictions on plastic waste introduced in 2018 had a serious impact on this waste trade: until then, a third of

[262] "In 1992 Bangladesh received 1000 tons of copper smelter furnace dust (containing high levels of lead and cadmium) which was mixed with fertilizer by several US firms and individuals […]. But some Bangladeshi farmers had already spread it on their fields before they were made aware of its contents. The firms involved were eventually convicted by the US government".

[263] "Between September 2008 and May 2009, more than 1 500 tonnes of household waste described as plastics for recycling were exported in 89 containers from England to Brazil. The contents consisted of co-mingled plastics, tins, paper, cardboard, batteries, syringes, empty medical packaging, condoms, and soiled nappies. Reports prepared by the Brazilian authorities in July 2009 concluded that the containers violated Brazilian law and the Basel Convention. As a result, the Brazilian government lodged a formal complaint with the Basel Secretariat." (p. 61)

[264] "The global waste market sector from collection to recycling is estimated at USD 410 billion a year (UNEP 2011), excluding a very large informal segment. As in any large economic sector, there are opportunities for illegal earnings at different stages of legal operations, with both monetary and ethical implications. […] Illegal and illicit trade of waste takes advantage of weak spots, such as the low overall possibility of controlling the trade, the price of waste treatment, and the complexity of waste-related legislation." (p. 31)

the eight million tons/year of such waste from Europe was delivered to China, but since then at least some of it (around 40%) has been directed along other legal and illegal 'export routes' [Interpol, 2020].

- These problems also apply to a wider range of hazardous materials. The shipment of e-waste or toxic pesticides to developing and some Eastern European countries has become of particular concern [Cotta, 2020[265]; UNEP, 2020[266]; Comolli, 2021]. One of the general statements from the related UNEP study is especially remarkable: "Many toxic products are too easily accessible in the marketplace or on the Internet. The potential and real economic, social and environmental costs of the illegal trade in chemicals are far from trivial, and legitimate businesses, national economies, and human health and the environment are suffering the effects." [UNEP, 2020: p. 7] According to another assessment of trade records, a very large proportion of that which occurred during the period 2004-2019 was illegal in terms of the chemicals covered by the *Rotterdam Convention* [Zou et al., 2023: p. 1394].

2.3.4. Controlling the international transportation of dangerous goods

International agreements have been drawn up on the conditions for the safe transportation of dangerous substances moved via various modes and along different routes, including the prevention of environmental and other damages during such operations. Reference is made to these regulations in the chapter of this book on toxic heavy metals, but they generally address the carriage of a multitude of dangerous substances.[267]

- International safety rules applicable to such air, sea, rail, road, and river transport were developed within the framework of the relevant organizations, namely, IATA, ICAO, IMO, OTIF, and UNECE, respectively.
- These regulatory systems are increasingly harmonized with each other thanks to cooperation between the experts of the abovementioned organizations, including the use of terms related to substances dangerous to human health and the environment, and the general safety principles and conditions.[268]
- The international agreements on the safe transportation of dangerous goods were updated, complemented and tightened several times, and their compliance is also regularly monitored [IATA/DGR, 1953, 2022[269]; IMO/IMDGC, 1965, 2020[270]; OTIF/RID, 1980, 2021; ADR, 1957,

[265] "Two cases are analysed: trade in discarded electronic and electric equipment (EEE) between the EU and Africa and trade in plastic materials between the UK and China. This study shows that exports of used EEE and recyclable plastic materials exacerbate the environmental burdens of Global South countries while also exporting new environmental risks and social burdens." (p. 255)

[266] "Intensive production and use of pesticides correspond to the needs of the global agricultural industry, and the illegal trade varies according to the conditions in domestic and global markets. The illegal marketing of effective, but extremely toxic, restricted and banned pesticides, tends to expand with pest outbreaks, and the use of pesticides is projected to increase in light of climate change. Illegal pesticide use may also increase as agriculture expands." (p. 65)

[267] The regulation of the transport of radioactive materials and their waste is not discussed here. This issue is primarily dealt with under the aegis of the International Atomic Energy Agency (IAEA).

[268] Special provisions for carriage of environmentally hazardous substances; Special marking provisions for environmentally hazardous substances; Wastes means substances, solutions, mixtures or articles for which no direct use is envisaged but which are carried for reprocessing, dumping, elimination by incineration or other methods of disposal.

[269] DGR: Dangerous Goods Regulations.

[270] IMDGC: International Maritime Dangerous Goods Code.

2020; ADN, 2000, 2021[271]]. Transport safety obligations and restrictions apply to a wide range of toxic substances and pesticides.

- The most extensive and severe environmental damages connected to international transportation affairs have occurred during maritime shipping accidents (Section 2.4). For some international watercourses, specific agreements and guidelines were developed based on the conditions for the shipment of hazardous substances: their newer versions in the European region are already in line with the more general UNECE agreement (ADN) (for example, in connection with the Danube, the Rhine, and the Sava River). In other regions, similar cooperation was developed, for example, among the riparian states of the Mekong River [MRC, 2012].[272]

2.3.5. International emissions trading systems

Human-induced environmental releases of harmful substances include atmospheric emissions of gaseous pollutants, such as sulfur dioxide, an acidifying atmospheric pollutant (AAP), e.g., from coal-fired power stations. An emissions trading mechanism for such pollution was introduced in the USA, and then a similar international system was also created.

- The system for trading with sulfur dioxide emission entitlements determined for the companies concerned was established in the USA under the federal *Clean Air Act* (adopted in 1970 and amended in 1990). This was seen as a market-conforming instrument that allowed a company to avoid paying a fine imposed by the relevant state authority if its annual emissions allowance level was exceeded. Instead, the company could purchase the emission rights for the missing units from another company whose annual emissions would remain below the limit determined for it.
- The *Convention on Long-range Transboundary Air Pollution* (CLRTAP) was adopted in 1979 under the auspices of the United Nations Economic Commission for Europe. Under its 1994 protocol, sulfur emissions must be reduced more effectively than before, and the relevant time-bound, quantified emission reduction requirements were defined for each Party.[273] These obligations could also be fulfilled jointly by two or more Parties.[274]
- However, the transfer of part of the emission rights by one Party to another would also have meant a change in the location where these pollutants are emitted, with a subsequent influence on their transport in and deposition from the atmosphere and, in turn, the areal distribution of their surface-level acidifying effects. Additional conditions were adopted in 1997 to take these consequences

[271] "The Contracting Parties, desiring to establish by joint agreement uniform principles and rules, for the purposes of: (a) increasing the safety of international carriage of dangerous goods by inland waterways; (b) contributing effectively to the protection of the environment, by preventing any pollution resulting from accident or incidents during such carriage; and (c) facilitating transport operations and promoting international trade […] 1.4.1.1 The participants of the carriage of dangerous goods shall take appropriate measures according to the nature and the extent of foreseeable dangers so as to avoid damage or injury and, if necessary, to minimize their effects."

[272] "Inland navigation can contribute to making transport more sustainable, particularly when it substitutes for road transport. But inland shipping can also have considerable environmental impacts. Concerns in the Mekong River include water pollution from shipping accidents, disposal of waste and wastewater from vessels as well as the overall operations of vessels, ports, ferry crossings, refueling stations and petroleum terminals along with the carriage, handling and storage of dangerous goods." (p. xv)

[273] The Oslo Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on further reduction of Sulphur emissions, 1994: (Art. 2.1 and Art. 2.2) "The Parties shall control and reduce their sulphur emissions in order to protect human health and the environment from adverse effects, in particular acidifying effects […] As a first step, the Parties shall, as a minimum, reduce and maintain their annual sulphur emissions in accordance with the timing and levels specified in annex II." In annex II, time-bound sulphur emission ceilings and percentage emission reductions were set for each Party.

[274] "The Parties to this Protocol may […] decide whether two or more Parties may jointly implement the obligations set out in annex II." (Art. 2.7)

into account,[275] but these 'complications' ultimately led to this sulfur pollutants emissions trading opportunity not being applied by the Parties.

When it turned out that the ozone layer was endangered by the emission of some synthetic compounds, international agreements were elaborated to address this hazard. The *Montreal Protocol on Substances that Deplete the Ozone Layer* was adopted in 1987 under the *Vienna Convention for the Protection of the Ozone Layer* (VCPO, 1985) with the ultimate objective of eliminating the emissions of ozone-depleting substances (ODS).

- In this case, the decisions on the Parties' obligations were not associated with the practically uncontrollable emission levels (as an 'end-of-pipe' approach), but involved setting very concrete and substantial reduction targets for the consumption and production of such substances (first, for five types of freons and three types of halons) [VCPO/MP, 1987: Art. 2, par. 1-4]. (Later, these provisions were gradually tightened, see Chapter 3).
- One of the provisions of this *Protocol* allowed the transfer of part of "production in excess of the limits set out" for a Party to another Party so that the latter could then use this additional quantity of production entitlements to remain below its production-related limits (Art. 5).[276] The first such bilateral trading agreement was concluded between Australia and New Zealand.

In accordance with the 1992 convention on climate change (UNFCCC), the stabilization of greenhouse gas (GHG) concentrations in the atmosphere should be achieved to prevent dangerous anthropogenic interference with the climate system. This danger is caused by the increasing human-induced emissions of gaseous substances controlled by this *Convention* and the subsequent legal instruments. An international cooperation mechanism for reducing the emissions of greenhouse gases, somewhat similar to the international mechanisms for regulating trade in hazardous chemicals and the aforementioned trading schemes for air pollutants, was introduced.

- The *Convention* only generally allowed Parties representing developed countries and 'countries with economies in transition'[277] listed in its Annex I (hereinafter referred to as 'Annex I Parties') to fulfil jointly their commitments related to greenhouse gas emissions and sinks.[278] The 1997 *Kyoto Protocol* not only confirmed this possibility but also defined three variants for such cooperation. These 'Kyoto flexibility mechanisms' included (i) international emissions trading (IET), (ii) 'joint implementation' (JI), and (iii) a special form of cooperation between the developed and developing countries called the Clean Development Mechanism (CDM). The latter two were 'project-based' collaboration forms. Four years later, the specific rules could be finally agreed upon for these instruments (at the meeting of the Parties held in Marrakesh).[279]
- Emissions trading between two Annex I Parties meant transferring emission allowances of greenhouse gases from one Party to another under certain conditions [UNFCCC/KP, 1997: Art. 17]. A surplus of transferable/tradeable 'quotas' could arise in a country, for example, through reductions in fossil fuel-based energy production. The first such trading transaction took

[275] Decision 1997/1 on rules and conditions for joint implementation under the Oslo Protocol (ECE/EB.AIR/53, Annex I).

[276] "Any Party whose calculated level of production in 1986 of the controlled substances in Group I of Annex A was less than twenty-five kilotonnes may, for the purposes of industrial rationalization, transfer to or receive from any other Party, production in excess of the limits set out in paragraphs 1, 3 and 4 provided that the total combined calculated levels of production of the Parties concerned does not exceed the production limits set out in this Article."

[277] "Countries that are undergoing the process of transition to a market economy."

[278] "The developed country Parties and other Parties included in annex I […] shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. […] These Parties may implement such policies and measures jointly with other Parties …" [UNFCCC, 1992: Art. 4, par. 2(a)]

[279] (i) "Modalities, rules and guidelines for emissions trading", (ii) "Guidelines for the implementation of Article 6 of the Kyoto Protocol", (iii) "Modalities and procedures for a cdm, as defined in article 12 of the Kyoto Protocol".

place in 2002 between Slovakia and Japan. (The European Union emissions trading system was established in 2003 as a component of the Community's climate policy portfolio.[280])

- 'Joint implementation' generally meant that if a developed country Party implemented an investment project in another Party representing a country with an 'economy in transition' to reduce emissions to or increase removal of GHG from the atmosphere, the former Party could, as compensation, count the emission reduction units thus generated as part of its obligation specified in the *Kyoto Protocol* [UNFCCC/KP, 1997: Art. 6]. Within the framework of the Clean Development Mechanism (CDM), 'certified emission reduction credits' from a project implemented in a developing country and supported by a developed country Party could contribute to the latter's meeting its emission reduction commitments [UNFCCC/KP, 1997: Art. 12].
- The 2015 *Paris Agreement* also provided for the possibility of (i) emissions trading and (ii) project-based cooperation. These procedures included the facilitation of the fulfilment of the emission-reduction-related commitments of a Party (i) which was the 'buyer' of the quotas ("the use of internationally transferred mitigation outcomes") or (ii) whose public and private entities were authorized to implement some activities/investments that "contribute to the reduction of emission levels in the host Party" (i.e., in the country of another Party, similar to the CDM procedures) [UNFCCC/PA, 2015: Art. 6.2, Art. 6.4]. It took six years to reach a consensus on the relevant rules for the implementation of these mechanisms (at the meeting of the Parties held in Glasgow in 2021).[281]
- Many experts consider these emissions trading systems to be beneficial from an economic perspective, while others object to their application from an environmental ethics perspective, because such cooperation actually amounts to trading in 'pollution rights'. For this reason, it has become particularly important that these instruments were intended to be only complementary, meaning that States Parties should primarily reduce environmentally harmful emissions 'at home' by promoting less environmentally polluting/degrading production and consumption, and developing and applying 'environmentally friendly' technologies.

2.4. HAZARDOUS SUBSTANCES AND HARMFUL POLLUTANTS IN INTERNATIONAL AREAS

The increasing pollution and environmental release of hazardous substances (chemicals, pesticides, etc.) and wastes into the environment have become issues of international and then global significance, partly because these pollutants are transported far away from their sources and cause severe impacts even in areas beyond national jurisdiction. The contamination of these 'international areas' – the high seas, Antarctica, and outer space – has been going on due to numerous human activities for a very long time.[282] The increasing and perilous implications of this process may lead to the 'tragedy of the commons' as Garrett Hardin referred to it in his famous essay (specifically mentioning the oceans), but in this case, the participants do not utilize or

[280] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

[281] "Guidance on cooperative approaches referred to in Article 6, paragraph 2, of the Paris Agreement", "Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement".

[282] This chapter does not deal with pollutants emitted to the atmosphere, because the most critical issues of global significance in this broad area of concern are discussed in Chapters 1, 3, and 4 of this book.

take something from the 'commons', but instead add something to it that may lead to their 'tragedy' [Hardin, 1968].[283]

2.4.1. Pollutants and hazardous wastes entering the marine environment

A large amount of hazardous wastes and pollutants of various consistencies, resulting from human activities, are discharged into the territorial waters of maritime countries, their exclusive economic zones, and the high seas. Of these, the latter is considered a huge part of the 'global commons', that is, the common maritime space beyond national jurisdiction. The increase in this global environmental burden is largely related to the acceleration of the production and consumption of hazardous chemicals, waste generation, and environmental releases of pollutants worldwide since the middle of the last century. Many decades ago, Rachel Carson raised concerns about the contamination of the sea with dangerous substances (along with such 'assaults' by man on other components of the Earth's environment): "[T]he most alarming of all man's assaults upon the environment is the contamination of air, earth, rivers, and sea with dangerous and even lethal materials. […] The chemicals to which life is asked to make its adjustment are no longer merely the calcium and silica and copper and all the rest of the minerals washed out of the rocks and carried in rivers to the sea; they are the synthetic creations of man's inventive mind, brewed in his laboratories, and having no counterparts in nature." [Carson, 1962: pp. 6-7] Recently, much greater attention began to be paid to these contaminants involving a 'novel pollutant', i.e., plastic waste [Barnes et al., 2009[284]; UNEP/GEO, 2012[285]; Persson et al., 2022[286]].

Waste dumping at sea. The amount of waste, including hazardous waste, has increased rapidly with industrial development and urbanization. The dumping of a substantial portion of that waste in the marine environment was a long-standing and common practice of many countries.

- More than a century ago, and for a long time after that, a typical solution was to transport municipal or industrial waste from some areas of the US to coastal ports and then dump it in the nearby sea [Rogers, 1976].[287] This environmentally damaging activity also became significant in

[283] "[T]he oceans of the world continue to suffer from the survival of the philosophy of the commons. Maritime nations still respond automatically to the shibboleth of the 'freedom of the seas' […] the tragedy of the commons reappears in problems of pollution. Here it is not a question of taking something out of the commons, but of putting something in- sewage, or chemical, radioactive, and heat wastes into water; noxious and dangerous fumes into the air". (p. 1245)

[284] "Less than 60 years ago, the mass production of plastics started and now most items that people use, virtually anywhere on the planet are partly or wholly made of this inexpensive, durable material. Plastics have transformed the surface of the planet far beyond areas of human population density – fragments of all sizes are ubiquitous in soils to lake beds, from remote Antarctic island shores to tropical sea-beds."

[285] "The open oceans and deep-sea ecosystems […] exhibit a wealth of biodiversity. Larger, slow-growing, long-lived and heterogeneously distributed species are adapted to stable conditions in these environments, and are particularly sensitive to environmental stresses. Governance of areas beyond national boundaries is weak and fragmented, however, requires strengthening in preparation of increasing human activities …".

[286] "Chemicals at large, including plastics, have been identified as fulfilling the characteristics of a novel entity. […] Novel means new in the geological sense, that is, created, introduced, or recirculated by humans. […] After several decades of mass production, plastics are now ubiquitous across the planet. […] The production of plastic, and consequently, plastic waste, is predicted to grow beyond the efficacy of the mitigating strategies to fight plastic pollution globally […], there is a need for integrated and just cross-border solutions to address the problem with emissions of novel entities, such as plastic pollution."

[287] "Under the Supervisory Harbors Act of 1888 the United States Army Corps of Engineers possessed jurisdiction over removal of materials from the ports of New York, Baltimore and Hampton Roads, Virginia. For activities within the three mile territorial seas, Section 4 of the Rivers and Harbors Act of 1905 and Section 13 of the Rivers and Harbors Act of 1899 provided legal support for the exercise of some control. […] The Ocean Dumping Act has been in force since April of 1973 […]. There are eleven active industrial and municipal ocean dumping sites in the Atlantic Ocean and Gulf of Mexico." (pp. 3, 7-8)

other parts of the world – increasingly in developing countries since the 1970s [Rucevksa et al., 2015].[288] Preparations for the first world conference on the environment began in 1968, and marine pollution became one of the important topics. The UN Secretary-General referred to this problem in his report, urging more thorough analysis and preventive measures [UNSG, 1968].[289]

- At a conference held in Washington in 1971, Jacques Cousteau and Thor Heyerdahl gave powerful presentations, stating that the oceans were being threatened by pollution and other means in full swing, and pollutants from human activities had reached even the most remote parts of the oceans. It is worth quoting their own warnings verbatim. "The sea, as everybody today knows, is threatened. We generally restrain and reduce the scope of the question, the problem that the ocean faces, by speaking only of pollution. In fact, what we are facing is the destruction of the ocean by pollution and by other causes." [Cousteau, 1971: p. 3]. "[T]hree practical observations which have a bearing upon man's future: (1) the ocean is not endless; (2) there is no such thing as territorial waters for more than days at a time; (3) pollution caused by man has already reached the farthest section of the world ocean. […] What others dump at sea will come to your shores, and what you dump at home will travel abroad irrespective of national legislation." [Heyerdahl, 1971: pp. 44, 51]
- Much more dangerous than municipal and industrial waste was that from the chemical weapons that were sunk, for instance, in the Baltic Sea after the world wars [Tornero & Hanke, 2016]. The marine disposal of containers containing radioactive materials in the Atlantic and Pacific Oceans or the Arctic Ocean was also a risky procedure. For decades, several countries disposed of their radioactive waste this way [IAEA, 1999].

Emissions of pollutants at sea. Pollutants generated on ships and from economic activities at sea also contribute to the marine contamination 'in situ', particularly as a result of rapidly increasing maritime passenger and cargo traffic and a rise in marine fishing and mining.

- Contaminants (various sorts of wastes including mixed waste, sewage, and sewage sludge) 'produced' by the crew and passengers of cruise ships are often 'disposed of' en route – i.e., released into the sea. This phenomenon has become substantial, especially over the last few decades, due to the huge capacity of cruise ships ('floating cities'). Most of the wastes and even (more or less) hazardous substances produced on board and harmful to water quality and wildlife ended in the sea, meaning only a fraction of them were properly treated either on ships or in ports [Olson, 1994; Leous & Parry, 2005[290]].
- Petroleum derivatives (fuel, bunker oil, lubricating oil) stored and used on ships for their operation can leak or spill into seawater, i.e., may be discharged not as a result of an accident. The discharge of ships' ballast water into the sea during its replacement can also have severe consequences [Herz

[288] "Between 1970s and 1990s, toxic waste and nuclear waste in barrels were being dumped in the high seas or on land, typically in developing countries. Since the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter came into force in 1975, this trend appears to have slowed down. Later the Bamako Convention prohibited the dumping at sea of hazardous wastes. However, due to the shady nature of such dumping activities, it is difficult to know whether and to what extent this is still happening." (p. 43)

[289] "34. With respect to marine pollution, the initiative to develop a concerted interagency programme was taken three years ago through the ACC Sub-Committee on Marine Science and its Applications. This followed requests by some member countries for an active programme with respect to problems of increasing concern in some areas".

[290] "Marine debris can also originate out at sea. Dumping from cruise ships and other commercial vessels is such a source. According to the Ocean Conservancy, each cruise ship passenger can produce up to 85 gallons of so-called gray water and 10 gallons of sewage per day. Thus, the average cruise ship that carries 3,000 passengers can generate 255,000 gallons of wastewater and up to 30,000 gallons of sewage daily." (p. 258)

& Davis, 2002[291]; GBP, 2013[292]]. The increasing environmental implications of these activities were noticed in the first half of the last century, but it took several decades before steps were taken at the international level to mitigate them.

- Sea fishing has become so industrialized that there are now 'fish processing factories' floating in the seas, which often 'return' to the sea a huge amount of waste that is generated in the process (along with some preservatives), supplemented by abandoned or discarded fishing gear (increasingly made of plastic) [Herz & Davis, 2002].[293]
- Offshore oil and gas mining has become a major industry; moreover, there is growing interest in seabed minerals [Lange et al., 2014].[294] These activities also result in the release of pollutants, which primarily have a detrimental effect on marine life in the vicinity of these activities.

During accidents of ships that occur for natural and/or technical reasons, hazardous substances or cargo containing such materials may enter the sea. In addition, accidents on/with oil rigs can also contribute to such environmental harms.

- Older accidents involving cargo ships have been recorded, which, among their other harmful effects, have had grave environmental implications. In 1917, the collision of a French and a Norwegian ship – the 'screw steamships' *Mont Blanc* and *Imo* – off the coast of Canada, and the subsequent explosion, claimed many human lives, and the harmful effects of the toxic explosive (cordite) carried by the French ship that spilled into the sea persisted for a long time. In 1934, a Russian tanker ran aground near the Spanish town of Camelle, broke in two, and spilled 11,000 tons of crude oil into the sea. In 1957, the French ship *Janina* caught fire and sank, polluting the sea off the Spanish city of Vigo with ten thousand tons of oil.
- In terms of marine pollution resulting from accidents, the 'scale change' from the late 1960s onwards was brought about by oil-carrying supertankers and container ships with much greater capacity than before. In 1967, the British *Torrey Canyon* hit a reef near Cornwall, spilling over a hundred thousand tons of (Kuwaiti) crude oil into the sea. This was followed by a series of tanker accidents from the 1970s onwards, such as the 200,000-ton oil spill from the *Amoco Cadiz* off the French coast in 1978 and the *Exxon Valdez* tanker oil spill of a similar magnitude off Alaska in 1989. Moreover, the latter occurred in a particularly sensitive area from an ecological point of view [Csatlós, 2009]. Other hazardous cargoes have also been 'lost' at sea: in 1993, the French cargo ship *Sherbro* was caught in a storm off the French coasts, and some of its containers, filled with several tons of toxic pesticides, capsized into the sea.
- Maritime cargo traffic has increased, but instances of major pollution resulting from accidents, including oil spills, have decreased due to international agreements and safety measures

[291] "Oil and oily waste discharges can result from collisions, groundings, fueling operation spills, and bilge pumping. But it is estimated that nearly one-third […] of petroleum products that reach the world's oceans each year is the result of marine transportation discharges unrelated to collisions and other accidents". (p. 11) "Cruise ships and other large vessels such as tankers and bulk cargo carriers use a tremendous amount of ballast water to stabilize the vessel. Ballast water is often taken on in the coastal waters of one region and discharged at the next port of call. It is estimated that ballast water transports at least 7,000 different marine species each day around the world […]. Ballast water discharges invasive species into some of the most sensitive waters in the world". (p. 17)

[292] "While ballast water uptake and discharge operations are mostly performed in ports, they can also occur at sea. […] The diversity of organisms conveyed by a ship is related to the geographic range of its trade routes. When species are able to survive the voyage and reach a new biogeographic region, their release in ballast water creates a hazard." (p. 4)

[293] "Entanglement in fishing line, wire, and plastic mesh and strapping, and ingesting plastic, Styrofoam, and other materials represent serious threats to marine life; they can damage an animal's digestive tract, cause starvation by blocking food intake, and inhibit growth, molting, reproduction, buoyancy, and, ultimately, survival." (p. 18)

[294] "Offshore oil and gas production has become routine. There are currently around 900 large-scale oil and gas platforms around the world. Over time, engineers have penetrated ever greater depths, for with oil prices rising, deepwater oil and gas production, although costly, is now a lucrative business." (p. 10) "Sea-floor mining. Diamonds, gravel and sand have been extracted from coastal waters for decades. To meet the growing demand for metals, there are plans to mine the ores found in the form of manganese nodules, cobalt crusts and massive sulphides at depths of up to 4000 metres". (pp. 53-54)

[UNEP/IRPTC, 1992; ITOPF, 2022[295]]. However, such damages have not been eliminated, as may be illustrated here with just one recent example: the *Grand America* caught fire about a hundred nautical miles from the Bay of Biscay in 2019, spilling two thousand tons of bunker oil into the sea, and some of its containers holding hazardous materials were also 'swallowed' by the deep. Offshore oil rigs have also multiplied: among the related accidents, the case of the Deep Horizon stands out. This rig caught fire in 2010 following an explosion, and due to the subsequent continuous oil leak, several hundred thousand cubic meters of oil spilled into the Gulf of Mexico.

Land-based activities are the source of large volumes of contaminants being released into the marine environment. Many legal or illegal waste dumps (landfills) have been established in coastal areas and along riverbanks, but a wide range of pollutants can enter the seas in many other ways and from much further afield.

- Significant sources of marine pollutants and hazardous wastes are land-based (i.e., come from ports and coastal and more remote inland areas). These include inadequate waste management operations, industrial and other activities (e.g., oil refining), and less frequently, industrial accidents [Farrington, 1985[296]; Leous & Parry, 2005[297]].
- In addition to atmospheric transport processes, a large amount of pollutants reach the seas through rivers [Schmidt et al., 2017].[298]

Whatever the source of contaminants in the seas, a significant proportion of them accumulate there, and their harmful effects may add up. In particular, the global plastic pollution of the seas is growing extremely rapidly, and the widely studied adverse effects of various other substances on marine life also include those caused by petroleum products.

- The harm caused by oil pollution has been studied for a long time [Blumer et al., 1970[299]; UNEP/IRPTC, 1992]. Recently, more attention has begun to be paid to the effects of other hazardous pollutants, including plastics. Plastic waste that ends in the sea breaks down into small pieces (forming 'microplastics'), floats in the water layer near the surface, and enters the food chain of marine organisms [OSPAR, 2007[300]; Gubek, 2016]. Hazardous and noxious substances (HNS) (e.g., toxic pesticides), which are most often transported in closed containers, are much less likely to be released into the sea, but if this happens, the consequences are much more serious than those of oil spills [Purnell, 2009; Galieriková et al., 2021].

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[295] "From 1970 to 2021, approximately 5.87 million tons of oil were lost as a result of tanker incidents globally. However, there has been a significant reduction in the volume of oil spilled throughout the decades." (p. 7)

[296] "Land based sources industrial effluents, municipal sewer effluents, marine tanker terminal and dry dock operations, and urban runoff account for more than a third of the total input […] of petroleum hydrocarbons into the marine environment" (pp. 4-5)

[297] "Approximately 80 percent of marine debris originates on land. Stormwater runoff, ineffective sewage treatment facilities and landfills are the primary sources of terrestrial debris. Since landfills are not meant to retain water, extensive drainage systems collect excess fluids and channel them into ditches located at the base of the landfill. Various types of debris, such as plastic fragments, can easily be transported through these conduits and into municipal sewers where they are discharged into coastal water bodies. Inadequate coverage of landfills can also result in marine debris" (p. 258)

[298] "Plastic debris loads, both microplastic (particles <5 mm) and macroplastic (particles >5 mm) are positively related to the mismanaged plastic waste (MMPW) generated in the river catchments. […] Using MMPW as a predictor we calculate the global plastic debris inputs from rivers into the sea to range between 0.41 and 4 × 106 t/y." (p. 12246)

[299] "It had then been suggested that hydrocarbons from oil pollution might be incorporated into marine organisms where they would persist […]. Another critical finding is the persistence of essentially unaltered fuel oil in the sediments two months after the spill. […] The gradual release of the oil with its high content of strongly toxic aromatic hydrocarbons from the sediments into the water column may pollute the water and the shellfish long after the actual accident." (p. 10)

[300] "Solid waste in the marine and coastal environment causes environmental, economic, safety, health and aesthetic problems. […] Plastic and polystyrene items are consistently found to be the main contributor to marine litter all over the world. […] Plastic items eventually break down into very small fragments and fibres […]. These fragments and fibres can be ingested by marine organisms and may move up the food chain." (pp. 14–15)

- The total amount of waste entering the sea each year was previously estimated at several billion tons, and of this, the most rapid increase was in plastics [UNEP-IOC, 2009[301]; IUCN, 2014; UNEP, 2014[302]]. One sign of this was the discovery of a vast and constantly growing garbage vortex – a large component of which was plastic waste – in the Pacific Ocean, created by ocean currents (sometimes called the 'Great Pacific Garbage Patch'). Several unsuccessful attempts have been made to eliminate this astounding 'patch' that has made it even more obvious that global waste, including the flood of plastic waste, needs to be curbed instead of trying to find an 'a posteriori' solution, i.e., cleaning up the environment from these pollutants [Moore, 2003[303]; Law et al., 2014; Dabrowska et al., 2021[304]].

International cooperation intended to investigate increasing marine pollution – as with so many other globalizing environmental issues – began in the middle of the last century following the recognition of the rapidly growing harmful effects of the 'Great Acceleration'.

- In the late 1960s, following the first major marine oil spills, the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the Intergovernmental Maritime Consultative Organization (IMCO)[305] launched research programs to explore the effects of and provide a scientific and technical basis for possible interventions to prevent and manage large-scale environmental pollution with hazardous substances. (This matter has also been addressed by IOC programs such as LEPOR and GIPME.)[306] Environmental pollution with radioactive wastes has also begun to be addressed in more depth within the framework of relevant international organizations (IAEA, OECD/NEA). Other UN institutions and international organizations have devoted attention to these marine pollution issues, as well. Therefore, in order to ensure more effective cooperation between all the institutions concerned, a joint Expert Panel was established in 1969 (GESAMP).[307]
- The first UN conference on the environment in 1972 (UNCHE) emphasized the need for more detailed observations in this area of concern. As a result, the establishment of a global ocean observation system (IGOSS) and the development of a project for monitoring marine pollution were launched (MAPMOPP).[308] The decision-making body of the then-established United Nations Environment Programme also considered these tasks urgent [UNEP, 1973]. Yet it took nearly two decades for this multifaceted, global system to emerge, covering marine pollutants as well (GOOS).[309]

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[301] "Estimates for the rate of litter accumulation in the world's seas and oceans vary substantially. The highest estimates suggest accumulation rates as high as 7 billion tonnes […] the lowest estimate of 6.4 million tonnes per annum […]. Irrespective, it is generally agreed that both the current levels and the rates of input are increasing".

[302] (4.) "Recognizes that plastics, including microplastics, in the marine environment are a rapidly increasing problem due to their large and still increasing use combined with the inadequate management and disposal of plastic waste, and because plastic debris in the marine environment is steadily fragmenting into secondary microplastics".

[303] "For the past fifty years or so, plastics that have made their way into the Pacific Ocean have been fragmenting and accumulating as a kind of swirling sewer in the North Pacific subtropical gyre." (p. 47)

[304] "The Great Pacific Garbage Patch (GPGP) is the largest of the five offshore plastic accumulation zones in the world's oceans […]. Over 75% of the GPGP mass was carried by debris larger than 5cm and at least 46% was comprised of fishing nets. Microplastics accounted for 8% of the total mass". (p. 3)

[305] The predecessor of this organization was decided upon in 1948, and it was renamed in 1982 (Inter-Governmental Maritime Consultative Organization, IMCO 1948–; International Maritime Organization, IMO 1982–).

[306] Long-term and Expanded Programme of Oceanic Exploration and Research (LEPOR, 1969–); Global Investigation of Pollution in the Marine Environment (GIPME, 1976–)

[307] Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP, 1969-): FAO, IAEA, IMCO, UNESCO/IOC, WHO, WMO; the UNEP participated in this cooperation after its establishment (1972-).

[308] Recommendation 90: "It is recommended that the Intergovernmental Oceanographic Commission, jointly with the World Meteorological Organization and, as appropriate, in co-operation with other interested intergovernmental bodies, promote the monitoring of marine pollution, preferably within the framework of the Integrated Global Ocean Station System (IGOSS) […], with advice from the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP)". [UN, 1972]

[309] Global Ocean Observing System (GOOS, 1991-)

- Other organizations and international networks were also actively involved in these activities: the 'consultative process' on marine plastic pollution (UN/ICP), the global platform for coordinating the development of marine litter management methods (GPML), the 'e-waste coalition' (EMG/EWC), the UN expert group dealing with marine litter and microplastics (EMG/AHEG), the IUCN and Greenpeace. Of particular note are the databases of organizations that have archived key information on serious maritime accidents (ITOPF, CEDRE).

International recommendations, programs, and agreements have been established with the aim of preventing or at least minimizing marine pollution and mitigating the damage thus caused. Of these, those that are global in scope are reviewed below, although the consequences of such incidents occurring in regional seas do not necessarily stop at their borders.

- The 1972 UN conference not only proposed the establishment of a global observation system, but also made recommendations for the prevention of marine pollution and waste dumping, and approved the respective principles that were incorporated not much later into the relevant conventions [UN, 1972].[310] The global agenda for sustainable development, adopted two decades later, devoted an entire chapter to tasks related to the seas, urging, among other things, the more effective implementation of relevant international agreements already in force at the time and in addition, the development of international regulations to curb pollution from land-based activities [UN, 1992].[311] After that, this topic was included on the agenda of the UN General Assembly every year and at the subsequent world summits on sustainable development (1997, 2002, 2012, 2015), where the situation – primarily the implementation of the formerly approved policy and legal instruments – was assessed and the actions to be taken were specified.
- To protect the marine environment, special programs were developed that were applicable to several critical issues and aligned with the policy recommendations of the 1992 UN conference. As mentioned above, a major proportion of all marine pollutants does not come from ships, but from land. According to the *Global Programme of Action* adopted in 1995, efforts should be made to ensure that waste and sewage from land-based activities do not enter the seas [UNEP/GPA-LbA, 1995].[312] The *Globally Harmonized System of Classification and Labelling of Chemicals* (GHS), approved in 2002/2003, is also applied to the maritime transport of such hazardous substances. The new global sustainable development agenda has set specific deadlines for reducing this pollution and eliminating waste dumping [UN, 2015].[313] In 2018, an action plan to combat marine plastic pollution was approved, and a strategy to reduce greenhouse gas emissions from cruise ships was developed in line with the *Paris Agreement* on climate change (IMO/MPL; IMO/GHG).[314] The former was supplemented in 2021 with the ambitious strategic goal of completely eliminating this plastic waste stream by 2025.
- The 'overture' to the global legal instruments dealing with or containing provisions on marine pollution was marked by the 1954 *International Convention for the Prevention of Pollution of the Sea by Oil* (with rather limited scope), and then the 1958 *Convention on the High Seas*. The latter required that the acceding States take measures to avoid oil pollution and the dumping of radioactive waste at sea [CHS, 1958: Art. 24, 25]. With the rapid upsurge in maritime traffic since

[310] *Action Plan*: Recommendation 86 "(a) Accept and implement available instruments on the control of the maritime sources of marine pollution; […] (c) Ensure that ocean dumping by their nationals anywhere, or by any person in areas under their jurisdiction, is controlled and that Governments shall continue to work towards the completion of, and bringing into force as soon as possible of, an overall instrument for the control of ocean dumping". *Report*: Annex III. "General principles for assessment and control of marine pollution".

[311] Chapter 17. Protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of their living resources.

[312] Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA-LbA).

[313] (14.1) "By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution". (6.3) "By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials".

[314] IMO Action Plan to Address Marine Plastic Litter from Ships; IMO Strategy on Reduction of GHG Emissions.

the 1960s, both unintentional (accidental) and intentional (dumping) pollution events have increased. Previous regulatory instruments have been replaced by new and much more detailed regulations: the 1972 *London Convention* and its 1996 protocol on prevention of waste dumping followed by the 1973 *International Convention for the Prevention of Pollution from Ships* and its 1978 protocol which covered both non-accidental and accidental pollution in general [LC, 1972; LC/LP, 1996; MARPOL, 1973; MARPOL/MP, 1978: Annex V]. In line with the former instruments, the dumping of waste into the sea and the incineration of waste on ships were prohibited (with some exceptions). The convention specifying strict technical requirements for seagoing vessels also served to increase the safety of oil transport by large-capacity tankers [SOLAS, 1974]. The provisions of the latter were clarified and expanded several times by its amending protocols (1978, 1988).[315]

- The *UN Convention on the Law of the Sea*, the drafting of which began after 1972, was established more than forty years ago and has become the fundamental document for international cooperation related to the seas. This 1982 convention, which only entered into force in 1994, also defined the general requirements under which States should establish and enforce rules at the national and international levels – for areas under and beyond their jurisdiction – to prevent and mitigate the pollution of the marine environment and the resulting adverse implications [UNCLOS, 1982].[316] Its provisions cover all sources of pollution: pollutants from activities on land, on ships, at sea, and on the seabed, with particular attention to toxic, persistent, dangerous, and noxious substances, including their unintentional and intentional environmental releases.[317]
- Taking into account this comprehensive UN treaty (UNCLOS) and other previous legal instruments, a series of new agreements on specific marine pollution topics have emerged since 1990. Environmental pollution problems related to oil continued to be taken into account, in particular: conventions have been approved on the prevention of oil pollution caused by tankers and also on civil liability for damage resulting from the leakage or spillage of oil carried by them and from the fuel tanks of ships (IOPRC, 1990; CLC, 1992; CLC-BOPD, 2001). International regulations have also been adopted to prohibit the dumping of low-level radioactive waste at sea, to assign responsibility for the maritime transport of hazardous and noxious substances (HNS), and avoid environmental damage due to the improper management of ballast water (LC/LLRW, 1993; HNS, 1996, 2010; BWM, 2004).
- A more recent and significant development was the resolution to begin negotiations on an international agreement in 2022 to reduce global plastic pollution [UNEP, 2022: UNEP/EA.5/Res.14, par. 3]: "The United Nations Environment Assembly […], Decides that the intergovernmental negotiating committee is to develop an international legally binding instrument on plastic pollution, including in the marine environment". Some of the key factors to be taken into account to properly address this globalized hazardous process include the demonstration (i) "that plastics exert a detrimental impact on the environment" and (ii) "a comprehensive understanding of available substitutes, and effectively leveraging this knowledge, can significantly contribute to the formulation and implementation of strategies aimed at curtailing plastic consumption and mitigating the associated polluting impacts." [Aanasen, M. et al., 2024] It seems that both criteria have been more or less met (at least the replacement of plastics is increasingly being achieved in several applications), but it will probably be quite a long time

[315] Annex I. Regulations for the Prevention of Pollution by Oil: "double hull and double bottom requirements for oil tankers of 5,000 tonnes deadweight and above".

[316] Article 194 "1. States shall take, individually or jointly as appropriate, all measures consistent with this Convention that are necessary to prevent, reduce and control pollution of the marine environment from any source".

[317] Article 194 (3.): "The measures taken pursuant to this Part shall deal with all sources of pollution of the marine environment." Article 207: Pollution from land-based sources; Article 208. Pollution from seabed activities subject to national jurisdiction. Article 209: Pollution from activities in the Area[+]. Article 210: Pollution by dumping. Article 211: Pollution from vessels. Article 212: Pollution from or through the atmosphere. ([+]Area means the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction).

before global plastic pollution is significantly reduced. The other fundamental development is that in 2023, the preparation of the *Agreement on conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction* (under the *UN Convention on Law of the Sea*) was finalized, and the text of this legal instrument was adopted [UNCLOS/BBNJ, 2023].

* * *

Attention to marine pollution has increased – that is, to the release of increasing amounts of different hazardous substances and wastes into the marine environment, and the severe harm caused by them. International policy and legal instruments have been developed, and although the States Parties, intergovernmental and other international organizations have done much to implement them, the state of the marine environment continues to be seriously threatened by human activities. For some reason, several major seafaring states did not become Parties to the MARPOL Convention and the London Convention/Protocol. Illegal marine waste dumping has not stopped, a significant proportion of contaminants produced onboard ships still ends up in the sea, the amount of microplastics that threaten marine ecosystems is still increasing, and although oil pollution from tankers has decreased, particularly flagrant cases are still occurring, even recently [UNEP, 2016; Lau et al., 2020[318]; Koboevic, 2022; ITOPF, 2022[319]]. One of the goals of the UN Agenda 2030 on sustainable development, approved in 2015, is to significantly reduce marine pollution by 2025 [UN, 2015].[320] This was referred to in the UNEP General Assembly resolution, which suggested that especially the "discharge of litter and microplastics to the oceans" should be completely eliminated in the long term [UNEP, 2017]. A proper assessment of the actual and changing situation would require, above all, more accurate data. The provision of the latter would be fostered if the Global Ocean Observing System (GOOS), established in 1991, were extended to include monitoring of marine pollution.[321] Initiatives have been commenced to develop and apply technologies that enable the recovery and disposal of marine litter, but in reality, greater emphasis should be placed primarily on the compliance/enforcement of preexisting regulations concerning prevention. The fortieth anniversary of the *Convention on the Law of the Sea* provided a good opportunity to reinforce this priority [UN, 2021a]. As mentioned above, the most recent developments are the development since 2022 of a global agreement on controlling plastic pollution (however, at the time of writing, these negotiations have not yet been completed) and the adoption of the *Agreement on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction* (but which was not yet in force at the time of writing).

[318] "Plastic pollution is globally ubiquitous. It is found throughout the oceans, in lakes and rivers, in soils and sediments, in the atmosphere, and in animal biomass. This proliferation has been driven by rapid growth in plastic production and use […]. If plastic production and waste generation continue to grow at current rates […], the cumulative mass of ocean plastic could increase by an order of magnitude from 2010 levels by 2025". (p. 1455)

[319] "With regard to the volume of oil spilt during the last decade, low annual quantities compared to prior decades were recorded for most years. However, a single large spill in 2018 resulted in the largest annual quantity of oil spilt in 24 years being recorded […]. Also the spill amount for 2021 is the second highest estimate in the last ten years." (p. 17)

[320] "14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution."

[321] The idea of development of an Integrated Marine Debris Observing System was raised several years ago: "IMDOS will build on the positive experience of such successful programs as the Global Ocean Observing System (GOOS) and, after a setup period, may become a part of the GOOS." [Maximenko et al., 2019]

2.4.2. Protection of the Antarctic environment from waste and waste-management-related adverse effects

Due to the harsh conditions in Antarctica, not many people visited it until the 1990s: most of them during the 1957/1958 International Geophysical Year and at the research stations established thereafter. Observations conducted there contribute to the understanding of the global environmental system's functioning, with the best-known example being the discovery of the 'ozone hole' in 1984 by experts at the Halley Research Station. However, due to the specific characteristics of the region, almost everything necessary for the establishment and maintenance of the stations, the provisioning of personnel, their living conditions, and scientific research must be transported there. During the daily lives of team members and the use of research materials and equipment, solid and liquid waste of various qualities and quantities is generated. Adding to the burden on the natural environment is the booming Antarctic tourism of the last few decades.[322]

Contaminants in the Antarctic. The approximately seventy permanent and temporary research stations are visited by a total of a few thousand people each year. Only a few stations are located further away from the more or less ice-free coastal area, in the interior of the continent, such as a research station in the USA (right at the South Pole) and a Russian research station.[323] However, with the expansion of scientific activities, unintended harmful effects on the Antarctic environment have also increased.

- The sixth continent still bears many signs of environmental pollution from past decades of human activity, particularly near several abandoned or long-standing research stations. References to 'simple' solutions to the waste problem and wastewater treatment are found in the first well-documented report summarizing the results of six on-site inspections [ATS-Inspection, 1980].[324]
- Until the 1990s, solid waste was generally disposed of in one of three ways. Depending on the location of the station: it was incinerated, placed in a 'landfill', or dumped on an ice floe near the coast, which eventually drifted out to sea, gradually melted, and the waste on it 'disappeared' along with the ice that had transported it there [Stark et al., 2006]. This dumped waste, which includes hazardous components, and the untreated or poorly treated wastewater discharged from the stations into the nearby area or the sea, has had serious environmental impacts [Tin et al., 2009].[325]

The basic framework of the international regulatory system is the *Antarctic Treaty*, which was concluded by the States participating in the respective program of the International Geophysical Year [ATS, 1959]. Its scope covers the entire area south of 60 degrees south latitude – thus, in a legal (but not geographical) sense, this refers to the Antarctic, which includes Antarctica, areas covered by ice shelves, and some islands. It is an international

[322] Pollutants also enter this region through the atmosphere, one of the 'famous' examples of this being the identification of DDT in the bodies of penguins [Geisz, 2004], but the following only deals with contaminants generated or left behind in this area and their prevention, minimization, and treatment.

[323] USA: Amundsen–Scott South Pole Station; RF: Vostok Station (Станция Восток).

[324] U.K. Station – Rothera: "Solid waste is all burned, the resulting ash and waste is dumped into the bay. Raw sewage and waste water is piped into the bay."

[325] "Chemical contamination from abandoned waste disposal sites and past fuel spills are a legacy from when environmental management was less stringent prior to the entry into force of the Environmental Protocol in 1998". (p. 6)

area that is not under the jurisdiction of any State. Although several States have made claims to certain sectors of Antarctica, they have no way of enforcing them under the *Treaty* [Conforti, 1986].[326]

- The *Treaty* only referred to radioactive waste material, forbidding its disposal in Antarctica [ATS, 1959: Art. V]. Later on, the 1989 *Basel Convention* stipulated that no waste should be shipped to this area for disposal [BC, 1989: par. 4.6].[327]
- The imposition of general environmental requirements concerning human activities in and around Antarctica only followed the *Treaty* much later. They were set out in the *Protocol on Environmental Protection to the Antarctic Treaty*, adopted much later [ATS, 1991], including detailed regulations on local waste management (Annexes III and IV). (This protocol was adopted in Madrid, so it is sometimes referred to as the *Madrid Protocol* or *Madrid Environmental Protocol* for short.) In addition to minimizing waste production, the emphasis was on bringing 'back' as much waste generated in the region as possible to the country whose authorities were responsible for the operation of the research station, or to another country if that waste could be properly disposed of there.
- This legal instrument also addressed the elimination of previously left-behind waste and landfills ('legacy waste'). But in the case of each waste treatment procedure (i.e., for solid waste, waste water, and sewage), the possibility of applying a different 'solution' remained open due to the same permissive wording: "to the maximum extent practicable".
- Besides scientific observations and research, tourism has been on the rise since the 1990s. Special guidance has been issued for companies (tour operators) who organize Antarctic visits regarding the requirements for environmental protection and waste management [ATS, 1994].[328]

The implementation of international agreements? To ensure that the human presence in the Antarctic does not damage the natural environment of this region, it is essential to comply with regulations concerning the wastes generated there and environmental protection in general.

- Since the adoption of the *Madrid Environmental Protocol* in 1991 and its entry into force in 1998, there has been some improvement in the situation regarding the mitigation of the environmental impacts of research activities. However, a significant part of the 'legacy waste' that remains from the past is still unmanaged. This applies in particular to the elimination of landfills [Tin et al., 2009],[329] but among the acute problems, special attention has been paid to the fact that at the majority of stations, wastewater was released untreated into the environment [Gröndahl et al., 2008].[330]
- The reports of the on-site inspections undertaken since the enforcement of the *Madrid Environmental Protocol* show a 'nuanced' picture of the shortcomings identified at several stations [ATS-Inspection, 2001, 2016]. The state of compliance with environmental regulations

[326] "Between 1908 and 1940, seven states advanced territorial claims in Antarctica. The first claimant state was Great Britain; the last was Chile. The five other claimant states are Argentina, Australia, France, New Zealand, and Norway. […] the claimant states do not enjoy any rights superior to those enjoyed by the other states carrying out activities in Antarctica. The Antarctic Treaty grants privileges to the states that demonstrate their interest in Antarctica by conducting substantial scientific research activity there." (pp. 253, 258)

[327] "The Parties agree not to allow the export of hazardous wastes or other wastes for disposal within the area south of 60° South latitude, whether or not such wastes are subject to transboundary movement."

[328] "When in the Antarctic Treaty Area – Organisers and operators should […] dispose of waste materials in accordance with Annex III and IV of the Protocol. These annexes prohibit, among other things, the discharge of plastics, oil and noxious substances into the Antarctic Treaty Area; regulate the discharge of sewage and food waste; and require the removal of most wastes from the area."

[329] "In the ten years since the entry into force of the Environmental Protocol, there has been relatively little progress in implementation of the provision requiring all past and present waste disposal sites on land and abandoned sites of Antarctic activities to be cleaned up by the generator(s) of such wastes and the user(s) of such sites". (p. 23)

[330] "This study shows that despite the fact that Antarctica is the largest pristine wilderness on the planet, and is very sensitive to environmental disturbance, 52% of the 71 stations located there lack any kind of waste water treatment system". (p. 303)

is also recurrently assessed by the Committee for Environmental Protection (CEP), whose public documents contain cautious statements – i.e., those which rather suggest what should be done in the future in order to fully achieve the environmental protection goals [ATS-CEP, 2016; McIvor, 2019[331]]. Due to the problems thus identified, the waste management guidelines to be followed by all Parties were clarified in 2019.

- Meanwhile, the environmental impact of tourism is a growing concern. While only a few thousand people visited the region each year in the 1990s, tens of thousands now typically arrive in Antarctica on an annual basis. The two most relevant bodies, the Antarctic Treaty Consultative Meeting [ATS, 2019] and the International Association of Antarctica Tour Operators (IAATO), are paying more attention than ever to minimizing the related environmental burden, including the waste resulting from the growing tourism traffic.

* * *

The protection of the sixth continent and the wider Antarctic region is not sufficiently effective against the environmental pollution resulting from activities on research stations and tourism. Moreover, there are several signs of growing interest in the mineral resources of this region (however, any such activities are prohibited, except for scientific research).[332] Environmental observations and research continue, with international cooperation, but no consensus has been reached and no meaningful progress towards stricter environmental regulations, despite the fact that some of the Parties to the relevant international agreements and a number of non-governmental scientific and other nature conservation organizations consider this necessary.

2.4.3. Space debris

Over the past half-century, thousands of artificial satellites and other spacecraft have been launched, primarily into Earth's orbit, and to a lesser extent, to investigate other celestial bodies and the more distant regions of space. Based on their distance from Earth, the vast majority of these space objects are found in 'Low Earth Orbit' (or near-Earth orbit), up to 2,000 km away, or in the geosynchronous orbits located about 35,000 km above mean sea level, or in an orbit between these two, at an altitude of several thousand km.[333] Once a part of outer space has begun to be explored and used (occupied) by such satellites, responsibility should be taken for its condition – that is, for the intentional or unintentional effects of these human activities in space.

Whatever the purpose for which a spacecraft was launched, sooner or later it will end its 'career' and – unless it is designed for multiple uses – this artificial object, or parts thereof, will remain in space as debris for some time.

- The exploration and use of outer space is open to anyone, but it is essential to comply with the most basic rules. Of particular importance among these is the responsibility of all 'space-using' public organizations or private enterprises for the generation and management of space debris, primarily regarding any spacecraft they launch.

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[331] "The subject of clean-up has been considered since the first meeting in 1998 of the Committee for Environmental Protection (CEP) […]. Available information, however, including the reports of official inspections under the Antarctic Treaty and Protocol, suggests that considerable work remains to be done to fully realise the protection goals of the Protocol. The clean-up of waste disposal and abandoned work sites is identified by the CEP as a priority issue for its attention, within the broader topic of repair and remediation of environmental damage."

[332] "Any activity relating to mineral resources, other than scientific research, shall be prohibited." [ATS, 1991: Art. 7] "With respect to Article 7, the prohibition on Antarctic mineral resource activities contained therein shall continue unless there is in force a binding legal regime on Antarctic mineral resource activities …" [ATS, 1991: Art. 25, 5(a)]

[333] Low Earth Orbit (LEO); Medium Earth Orbit (MEO); Geosynchronous Orbit: Geosynchronous Equatorial Orbit (GEO), Geostationary Orbit (GSO).

- According to the renowned Hungarian space researcher and astronomer, Iván Almár: "The space debris problem is critical in two regions: on the one hand, in low Earth orbit (LEO), where valuable satellites, inhabited space stations and spacecraft are located, and on the other hand, near geostationary orbit (GEO). The latter […] represents great value because telecommunications or meteorological satellites placed here […] are suitable for continuous observation of certain surface areas and for continuous communication." [Almár, 2004]
- However, the amount of space debris and the risks arising from it are constantly increasing, especially in low-Earth orbits. Therefore, there is much to be done in this region within the framework of international cooperation [UNOOSA, 2019].[334]

The amount and sources of space debris and the associated risks. In addition to the approximately two thousand artificial objects currently operating in Earth orbits, this 'space environment' contains a multitude of previously launched but no longer operational satellites, as well as a huge amount of debris of various sizes and masses that has been detached from them or generated by collisions.

- The amount and spatial distribution of smaller pieces of space debris are estimated in different ways by NASA and ESA, among others. Larger items of debris measuring over 10 cm and smaller ones between 5 cm and 10 cm are continuously monitored by the countries that launch space objects.[335] The estimated amount of space debris around Earth [*Muñoz-Patchen, 2018*]: one hundred million micrometeoroids (1-10 mm), at least half a million small (1-10 cm), and a few tens of thousands of larger pieces of debris (over 10 cm in size).
- The vast majority of space debris is located at an altitude of 800-1,000 km from Earth. Pieces of it and space debris slightly further away may continue to orbit the Earth for a long time before gradually descending and being destroyed in the atmosphere. (Although smaller or somewhat larger pieces of space debris may reach the surface, as has occurred several times.)
- Space debris can be generated in many ways and for many reasons: during the launch of spacecraft, when the latter become inactive, as small or large pieces being detached from an object (e.g., pieces of paint and coatings), or when a spacecraft explodes or two objects collide [IADC, 2019; ESA, 2019[336]].
- In addition to space debris located above the Earth within a distance of a few tens of thousands of km, it is necessary to mention those no longer functioning devices that have travelled further into space, or whose whole, parts or debris are found on another celestial body, because these also belong to the category of space debris. Such remains are found primarily on the Moon, as well as on Venus and Mars.
- Not only does space debris generally pollute the space environment, but such fragments travelling around our planet endanger currently operational satellites, especially those in 'protected' near-Earth and geostationary orbits. Various methods are used to estimate the probability of such collisions, first of all in the case of objects functioning in low-Earth orbit, and to investigate the means of avoiding them. As the number of satellites and the amount of debris increases, the risk of collision grows, and a 'domino effect' may also occur, as a collision between two space objects can create a lot of new space debris [Torky et al., 2019].[337] It also has critical consequences when

[334] "While space helps us build resilience and accelerate sustainable development, we need to ensure it remains sustainable as a global commons. One problem that we are working to address is the increasing amount of space debris". (p. v)

[335] U.S. National Aeronautics and Space Administration (NASA): Orbital Debris Program Office (ODPO); European Space Agency (ESA): Space Debris Office; U.S. Space Surveillance Network (SSN); R.F. Main Space Control Centre (SKKP) / Центр Контроля Космического Пространства.

[336] Payload mission-related objects, Payload fragmentation debris, Payload debris, Rocket body, Rocket mission related objects, Rocket fragmentation debris, Rocket debris. (p. 8)

[337] "As a result of historical space operations and fragmentation, it is likely that the density of space particles has reached a critical level, where the rapid growth of space debris will continue with the increase in human work in space. Debris growth comes from a widely-expected increase in the number of collisions between a large number of space masses." (p. 83461)

a satellite explodes and breaks into pieces, or this occurs due to deliberate interference [IADC, 2019[338]; *Muñoz-Patchen, 2018*[339]]. An extreme version of the aforementioned 'domino effect' is known as Kessler syndrome. This refers to the claim that once a critical number of objects are present in low-Earth orbit, the probability of collisions will be multiplied due to the space debris generated by their collision, resulting in a chain reaction of collisions of space debris, practically turning low-Earth orbit into a 'debris belt' (a belt around the Earth saturated with space debris) [Kessler & Cour-Palais, 1978; Kessler, 1991[340]].

The development of international research and technological relations has contributed to the exploration of outer space, a better understanding of the Earth's environment with the help of satellites, and the development of various services (e.g., telecommunications). After a while, the potential collision of satellites and space objects, as well as the mitigation of risks due to space debris, also made international consultations and collaboration necessary.

- A new era of space exploration began in the late 1950s with the establishment and activities of international and intergovernmental organizations such as the International Astronautical Federation (IAF, 1951), the Committee on Space Research (COSPAR, 1958, a member of the ICSU/ISC), the International Academy of Astronautics (IAA, 1960, initiated by Theodore von Kármán), and the International Institute for Space Law (IISL, 1960).
- Shortly after the launch of the first artificial celestial bodies, i.e., after 1957, a UN resolution (1348 (XIII), 1958) established not only the general objectives and framework of cooperation, but also touched upon some principles of the joint use of outer space in addition to research. Based on this resolution, the UN Office for Outer Space Affairs and the Committee on the Peaceful Uses of Outer Space, for short, the UN Space Committee (UNOOSA, 1958; UNCOPUOS, 1959), and among the UN specialized agencies, the International Telecommunication Union (ITU) were the first to become involved in exploring the possibilities of using space (ITU, 1963).[341]
- The problems caused by the accumulation of space debris have been much more actively dealt with since the 1990s by the Inter-Agency Space Debris Coordination Committee (IADC, 1993), the aforementioned UN Space Committee, the ITU, the IAA Space Debris Committee (SDC), the COSPAR's Panel on Potentially Environmentally Detrimental Activities in Space (PEDAS) and the IAF Committee on Space Security (CSS).

Global regulation that addresses the space debris problem. Apart from organizational developments, the most fundamental developments regarding strengthening 'space safety' and coping with the space debris issue can be considered the adoption of the respective international legal instruments and non-binding guidelines.

- The *Outer Space Treaty* (OST) already referred to the importance of not causing contamination in the course of studying and exploring outer space [OST, 1967].[342] This was followed in 1979

[338] "The most common source of space debris is on-orbit break-ups of spacecraft or orbital stages. At the time of writing, more than half of catalogued objects, and the vast majority of all space debris larger than 5 cm in diameter stem from on-orbit break-ups." (p. 17)

[339] "At 49% of trackable debris, 'fragmentation debris', consisting of small pieces of matter from collisions between space objects or accidental explosions, is the largest source of trackable debris. Some of this debris was created by the intentional destruction of space objects. For example, in 2007 China intentionally destroyed one of its weather satellites to test an antisatellite missile, producing approximately 2,500 pieces of trackable debris, as well as many more small and untrackable pieces." (p. 237)

[340] "[C]ertain regions of low Earth orbit are already unstable. Most of the larger debris generated in these regions will be confined to the unstable regions. This is one of reasons they are unstable. However, smaller debris will be ejected to greater distances than large debris, and these unstable regions will act as an increasing source of small debris in all of low Earth orbit for centuries." (p. 1265)

[341] International Telecommunication Union (ITU): Extraordinary Administrative Conference (on space radio-communications), 1963.

[342] Article IX: "States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination".

by the *Moon Treaty*, which also defined general terms for preventing "the disruption of the existing balance" of the environment of the Moon and other celestial bodies in their exploration and use [Moon, 1979].[343]

- The *OST* received broad support from all states interested in space exploration, but the same cannot be said for the *Moon Treaty*, which was rejected by the USA and the Soviet Union, the two leading 'space powers' at that time. Ultimately, this Treaty was ratified by only 18 States. Előd Both (former director of the Hungarian Space Office) identified the reasons for this mainly in the possibility of the future expropriation of 'distant' resources [Both, 2016]. (The actual background to this controversial situation was only discovered much later [Wedenig & Nelson, 2023].)
- In addition to the above two legal instruments, the *Space Liability Convention*[344] should be mentioned, which also applies to damages caused by space debris [SLC, 1971].

Global recommendations and guidelines exist solely with the aim of preventing and reducing the generation of space debris, meaning there are no mandatory regulations to be followed to achieve these goals.

- The inter-agency committee first developed such recommendations in 2002, which have been supplemented several times since then [IADC, 2019]. The first and later refined guidelines of the UN Space Committee were created in 2007, stemming from the initial version of IADC recommendations [UNCOPUOS, 2010]. The aim of these is to prevent or minimize the generation of space debris during the launch and operation of satellites, to avoid satellite collisions (which sometimes cause a lot of space debris), and to remove spacecraft from low-Earth and geostationary orbits after their missions.[345]
- The sustainability requirements of space activities call for the development of procedures that, in addition to previous recommendations, can be used to manage the increasing risks caused by space debris, at least in the long term [UNCOPUOS, 2019].[346]
- It is worth mentioning that the ITU and ESA have also published space debris regulations within their own jurisdiction, and most 'spacefaring states' also apply such national regulations.

The amount of space debris is increasing, despite the fact that the requirements concerning operational safety, the expected lifespan of satellites, and the fate of satellites and launch vehicles after their use are already taken into account during design. The international agreements and recommendations to date, therefore, do not appear to be sufficient to mitigate the space debris problem.

- Plans and ideas have been put forward to subsequently reduce the amount of space debris (e.g., its 'collection' and subsequent disposal), but due not only to the technical complexities but for economic- and property-rights-related reasons, there has been no serious progress in this area

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[343] Article 7: "1. In exploring and using the Moon, States Parties shall take measures to prevent the disruption of the existing balance of its environment, whether by introducing adverse changes in that environment, by its harmful contamination through the introduction of extra-environmental matter or otherwise." Article 1: "1. The provisions of this Agreement relating to the Moon shall also apply to other celestial bodies within the solar system".

[344] Convention on International Liability for Damage Caused by Space Objects.

[345] "(1) Limit debris released during normal operations. (2) Minimize the potential for break-ups […] (3) Limit the probability of accidental collision in orbit. (6) Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission. (7) Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission."

[346] (D.2.) "Investigate and consider new measures to manage the space debris population in the long term. […] 3. Investigation of new measures could include, inter alia, methods for the extension of operational lifetime, novel techniques to prevent collision with and among debris and objects with no means of changing their trajectory, advanced measures for spacecraft passivation and post-mission disposal and designs to enhance the disintegration of space systems during uncontrolled atmospheric re-entry."

[Singh, 2020].[347] The most urgent task is removing unnecessary objects from the two 'protected' orbits (LEO, GEO) as indicated by these international guidelines.

- According to these guidelines, no later than 25 years after the end of its mission, a satellite should no longer remain in low-Earth orbit, and at least 90% of them should be disposed of along with other space debris [IADC, 2019] – otherwise this area of space could become so saturated that the risk of collisions may increase excessively. Regarding the other space orbit (GEO), satellites that are no longer in use should 'leave' from there, and although there are positive signs in this respect, overall, since 1957 (the beginning of the 'space age'), the number of operating and non-operating artificial objects around the Earth has increased continuously [ESA, 2019].[348]

* * *

The problem of space debris has also become of global significance and requires more decisive, internationally coordinated measures for its management. It would be reasonable to include provisions aimed at preventing and reducing the generation of space debris in binding international regulations related to or similar to the *Outer Space Treaty*, provided that all the respective countries accept and comply with them. The need to address this issue as an essential precondition for the safety of outer space activities was highlighted by the UN resolution adopted on the occasion of the UNISPACE+50 conference: "The General Assembly […] *Stressing* the need to ensure the long-term sustainability of outer space activities and, in particular, the need to address the significant challenge posed by space debris, and […], *Convinced* that ensuring that outer space remains an operationally stable and safe environment suitable for use by current and future generations would be consistent with the long-standing principles contained in the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies" [UN, 2018]. This requirement was also echoed in the framework of the *Space2030 Agenda* (adopted in 2021) [UNOOSA, 2024].[349]

2.5. THE GLOBAL POLLUTION PROBLEM: INTERCONNECTED WITH OTHER DANGEROUS ENVIRONMENTAL PROCESSES

The environmental issues discussed above and the relevant frameworks of international cooperation are not only interconnected with each other but also with other dangerous global environmental processes. An excellent and significant example of the former is the collaboration of the institutions involved in the implementation of global chemical conventions. The growing pollution problem, together with the threats of climate change and biodiversity loss, has lately been dubbed the "triple planetary crisis". One of these phenomena, multifaceted pollution, has recently received much greater attention because it is considered less comprehensively studied and controlled than climate change and biodiversity loss, which have been the subject of extensive international scientific and policy cooperation and addressed by global programs and agreements.

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[347] "Various space removal methods have been suggested by many researchers. However, not a single piece of space junk has been eliminated to date from space only because of the complication and high cost of the mission." (p. 233)

[348] "The amount of objects, their combined mass, and their combined area have been steadily rising since the beginning of the space age, leading to the appearance of involuntary collisions between operational payloads and space debris." (p. 77)

[349] "Overarching objectives 4: 4.6. Enhance the safety of outer space operations as a contribution to the long-term sustainability of outer space activities. […] 4.8. Enhance, within the framework of the Committee, the exchange of information on space objects and events, as well as the discussion on the prediction and prevention of potential collisions."

2.5.1. The triple planetary crisis

> The concept of a "triple planetary crisis" has attracted increasing emphasis since 2020. This term was introduced and discussed in UN forums to refer to the intersecting global environmental threats of pollution, climate change, and biodiversity loss.[350]

The assessment reports[351] of UNEP, IPBES, and IRP, published in 2019, highlighted the contradictory situation that, while major international policy decisions were concluded during recent decades to tackle global-level biodiversity loss, anthropogenic climate change, and at least some of harmful pollutant emissions (e.g., persistent organic pollutants), these dangerous environmental processes have continued to intensify due to continuing human interventions.

- The new medium-term strategy of the UNEP was elaborated in 2020 and adopted by the UN Environmental Assembly in February 2021 [UNEP, 2021b]. Its situation analysis highlighted that "the world is facing three major environmental crises: climate change, biodiversity loss and pollution. These are all largely driven by human activity and unsustainable patterns of consumption and production. Tackling these crises is critical to improving the health of the environment, as well as social and economic health". The corresponding interconnected long-term objectives were specified to achieve (i) climate stability (in line with the 2015 *Paris Agreement*), (ii) harmony between man and nature (as reinforced by the vision of the post-2020 biodiversity strategy, i.e., the *Kunming-Montreal Global Biodiversity Framework*), and (iii) a pollution-free planet (in conformity with the UNEP's action plan '*Towards a pollution-free planet*' approved in 2019).
- The focus on these environmental issues was underlined in 2020 by the Executive Director of UNEP, who recalled the recent assessments concerning the acceleration of global warming, the rapid decline of nature, and the increasing pollution: "The science is crystal clear that we are putting extreme pressures on the planet. […] The common thread, in a sense, that runs through this triple planetary crisis is unsustainable production and consumption." (Inger Andersen: 'The triple planetary crisis: Forging a new relationship between people and the earth', speech delivered on 14 July 2020.) The UN Secretary-General echoed this sentiment: "we face a triple planetary emergency — a climate crisis, a nature crisis and a pollution crisis. […] Yet, we have solutions. We know what we need to do to reconcile humankind and nature." (António Guterres: speech delivered on 16 November 2020.)
- The scientific background and the policy measures necessary for managing these crises were presented in the publications of UNEP and UN University in 2021: *Making Peace with Nature – A scientific blueprint to tackle the climate, biodiversity and pollution emergencies* [UNEP, 2021c] and *Beyond Opportunism – the UN Development System's Response to the Triple Planetary Crisis* [UNU, 2021].

While these crises are interrelated, global pollution, including the environmental release of a multitude of hazardous substances, including so-called 'anthropogenic chemicals' (such as synthetic organic and other chemicals) has not yet been controlled by international policy and legal instruments as widely as the two other human-induced planetary processes.

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[350] As a matter of fact, such interrelations among global environmental processes were already analyzed by scientists earlier, quoting here only one example: "It is clear that human activities have led to intense multiple stressors acting together in many marine ecosystems. Most notably these are arising from overexploitation of biotic resources, climate change effects […] and pollution." [Rogers & Laffoley, 2013]

[351] UNEP, 2019: Global Environment Outlook (GEO-6) and Emissions Gap Report; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019: Global Assessment on Biodiversity and Ecosystem Services; International Resource Panel (IRP), 2019: Global Resources Outlook.

- This deficiency was clearly articulated by a team of researchers in their recent publication [Almroth et al., 2022: p. 1070]: "Earth and humans face a triple planetary threat of climate change, biodiversity loss, and pollution. These three interlinked environmental crises, all of which are destabilizing Earth's systems, require immediate evidence-based action. While international science-policy arenas for the co-production of actions for dealing with the first two threats largely exist, the pollution threat requires greater awareness of the planetary impacts and solutions."
- Similarly, the need to handle this threat was reaffirmed in relation to the 'planetary boundaries' theoretical concept, which specifically denotes pollutants such as the synthetic chemicals and substances among the 'novel entities' [Richardson et al., 2023: pp. 1, 6]: "Currently, anthropogenic perturbations of the global environment are primarily addressed as if they were separate issues, e.g., climate change, biodiversity loss, or pollution. This approach, however, ignores these perturbations' nonlinear interactions and resulting aggregate effects on the overall state of Earth's system. […] For many substances, the potentially large and persistent effects on Earth system processes of their introduction, particularly on functional biosphere integrity, are not well known, and their use is not well regulated. Humanity has repeatedly been surprised by unintended consequences of this release, e.g., with respect to the release of insecticides such as DDT and the effect of chlorofluorocarbons (CFCs) on the ozone layer."

2.5.2. Intersections among some global pollution and climate change problems

Several key factors pertaining to environmental emissions and the international regulation of pollutants are discussed in other chapters of this book and above sections of this chapter. With regard to the aforementioned 'triple planetary crisis' and its pollution dimension (which is considered particularly critical), some matters associated with the latter are presented below, which are interlinked with anthropogenic climate change.

The global waste problem is considered a major constituent of the global pollution crisis, which is closely linked to climate change through greenhouse gas emissions, specific aspects of which are taken into account under the respective international agreements.

- The greenhouse gas (GHG) emissions from waste-related sources have also been considered in the former climate change assessments [IPCC, 2007; Monni et al., 2008]. More recently, it was revealed that there has been an increase in the share of the former, especially from the incineration of waste (including plastic waste) [EC, 2018; CIEL, 2019].[352] It also turned out that the methane content of landfill gas released into the atmosphere has a greater total greenhouse effect than carbon dioxide emissions from all forms of waste management. (Methane emissions from wastewater are usually considered separately, less often together with those derived from solid waste.)
- While this environmental burden has decreased in developed countries, GHG emissions – including those from waste-related sources – have been growing globally, with only a temporary drop during the COVID-19 pandemic in 2020, before returning to their increasing trend (see Chapter 4 on climate change). The ultimate response, at least to the waste 'driver' of the climate change problem, is the 'zero waste' strategy, which has numerous components and benefits: "With its potential to dramatically reduce short-term methane emissions, and even function as a 'net-negative' sector, waste management can and should play an instrumental role in climate

[352] "It was estimated that plastics production and the incineration of plastic waste give rise globally to approximately 400 million tonnes of CO_2 a year." (EC, 2018: p. 6). "Globally, the use of incineration in plastic waste management is poised to grow dramatically in the coming decades." (CIEL, 2019: p. 3)

action. Zero waste systems deliver mitigation, adaptation, and additional benefits by source reduction for both organics and non-organic waste" [Gaia, 2022: p. 83].

- Actually, the 'reverse' effect (which is to some extent a 'rebound effect') has also been investigated, i.e., the influence of changing climatic conditions on waste production and management [Bebb & Kersey, 2003; Kaza et al., 2018]. "Climate change is an undesirable phenomenon whose negative impacts outweigh the positive impacts. The interaction between climate change and waste management is a complex one that is difficult to predict with precision." [Prakash et al., 2024: p. 154]

Waste-climate nexus: international cooperation and regulation. In its first report, the Intergovernmental Panel on Climate Change (IPCC) drew attention only to methane emissions arising from organic waste that has been landfilled; however, the second assessment report already included measures that would enable such emission reductions [IPCC, 1990; IPCC, 1995].

- It is also thanks to this latter report that, while the 1992 convention on climate change referred only in general to anthropogenic sources of greenhouse gas emissions, its 1997 *Kyoto Protocol* required Parties to address emissions from waste treatment ("solid waste disposal on land, wastewater handling, waste incineration, other") in addition to the other listed sectors/sources [UNFCCC, 1992; UNFCCC/KP, 1997: Annex A]. According to this legal instrument, developed countries were obliged first of all to reduce their methane emissions.[353]
- As early as in 2007, the IPCC reviewed the options for mitigating these emissions in a separate chapter, and the 2014 report repeatedly emphasized the importance of proper waste management due to the resulting climate policy and natural resource management benefits [IPCC, 2007; IPCC/WG-III, 2014[354]].
- Under the 2015 *Paris Agreement*, all Parties should report[355] on national plans and measures for contributing to meeting global climate policy goals starting from 2020; the formulation of detailed rules for fulfilling this obligation was finalized in 2018 [UNFCCC/PA, 2015; Faragó, 2019]. While most of the first such national reports mentioned waste-related emissions, only a few presented specific plans/interventions aimed at reducing them [UNFCCC, 2016: pp. 35-37].
- Other international organizations also deal with climate policies involving waste and waste management, like the World Bank and the United Nations Development Program, primarily through the support available to developing countries for handling these issues, and the FAO in connection with atmospheric emissions from food and agricultural waste. In addition to the fact that the United Nations Environment Program regularly publishes its assessments on global environment and the emissions of greenhouse gases (GEO, EGR), it also comprehensively analyzes the situation of the waste problem and, as part of this, its interaction with other environmental hazards [UNEP, 2010; UNEP/GWMO, 2015[356]].
- One of the fundamental obstacles to achieving international climate policy goals is that, as the volume of global waste continues to grow, the resulting emissions of greenhouse gases are also

[353] Each Party included in Annex 1 shall "(a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as: […] (viii) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy" (Art .2, par. 1).

[354] "Mitigation in the industry sector can also be achieved by reducing material and fossil fuel demand by enhanced waste use, which concomitantly reduces direct GHG emissions from waste disposal […]. Globally, only about 20 % of municipal solid waste (MSW) is recycled and about 14 % is treated with energy recovery while the rest is deposited in open dumpsites or landfills". (p. 82)

[355] Nationally Determined Contributions (NDCs).

[356] "Waste and resource management offers a number of opportunities for mitigating greenhouse gas (GHG) emissions across a wide range of industrial sectors." (p. 12)

expected to increase [Kaza et al., 2018].[357] Most of the initial national communications on plans for implementing the *Paris Agreement* did not include measures for reducing these emissions, despite some of these interventions being cost-effective and generating other benefits [Ross et al., 2018; Hanson, 2019]. This was underlined repeatedly by the IPCC in all its recent assessment reports. "Existing waste-management practices can provide effective mitigation of GHG emissions from this sector: a wide range of mature, environmentally-effective technologies are available to mitigate emissions and provide public health, environmental protection, and sustainable development co-benefits." [IPCC, 2007: Ch. 10] "Important options for mitigation in waste management are waste reduction, followed by re-use, recycling and energy recovery […] As the share of recycled or reused material is still low (e.g., globally, around 20 % of municipal solid waste is recycled), waste treatment technologies and recovering energy to reduce demand for fossil fuels can result in significant direct emission reductions from waste disposal" [IPCC/WG-III, 2014: p. 24]. The most recent report also referred to such cost-effective emission reduction options, including the 'waste sector' [IPCC, 2022].

Certain geological structures have proven suitable for storing hazardous materials. Accordingly, one way to 'treat' hazardous substances and wastes that are difficult to dispose of is to move them deep below the Earth's surface. This has become standard practice for hydrogen sulfide and radioactive waste; however, the application of this option for carbon dioxide is also being studied and tested in some places due to its rapidly increasing atmospheric concentration.

- Hydrogen sulfide (H_2S) is separated from the extracted crude oil or natural gas and, instead of – for example – being released into the atmosphere, it is disposed of "by injection into deep geological formations" [Bachu & Gunter, 2004]. Moreover, this procedure has proven to be more cost-efficient than desulfurization.

- A similar approach to injecting carbon dioxide (CO_2) into oil fields has been used for a long time to increase oil production [Pápay, 2011]. More recently, as part of potential climate mitigation policies, the feasibility of separating (capturing) carbon dioxide from the flue gas of fossil fuel power plants and storing it in suitable geological formations has been examined [Tihanyi & Csete, 2012[358]; Cebruceana et al., 2014[359]]. In addition, the opportunities for utilizing the 'captured' CO_2 are also being studied [Gabrielli, 2020].[360] One well-known application of such methods is the production of methanol, a research topic of György Oláh to whom a Nobel Prize in Chemistry was awarded [Molnár, 2017].

- If the aim with these two gases is to avoid their atmospheric emissions by injecting them into a natural underground medium and storing them there, then it is actually a matter of disposing of gaseous waste of industrial origin.

International aspects related to the underground storage of the aforementioned pollutants. Hydrogen sulfide subsurface injection did not have an international dimension, as this procedure was implemented only within the national borders of certain countries (e.g., Canada and the USA). But, in the case of carbon capture and storage or utilization, a similar solution has international implications, because of (i) the contribution of the potential slowdown in the increase in global

[357] "An estimated 1.6 billion tonnes of carbon dioxide–equivalent greenhouse gas emissions were generated from solid waste management in 2016. […] Without improvements in the sector, solid waste–related emissions are anticipated to increase to 2.6 billion tonnes of CO_2-equivalent by 2050." (p. 13)

[358] "The amount of CO_2 emitted by power and industrial plants is so large that trading it to other industries (e.g., chemical industry, food industry) is not a realistic idea. […] The only real alternative to 'eliminating' CO_2 is storage, final disposal. In principle, there are two possible solutions for the final disposal of CO_2: in underground storage tanks, or the oceans, [… but] the most suitable are the exploited oil and gas fields." (p. 233)

[359] "Fossil fuel power plants generate significant amounts of CO_2 emissions into the atmosphere, which are believed to be the main cause of climate change. Among CO_2 mitigation options, carbon capture and storage is considered the only technology that can significantly reduce the emissions of CO_2 from fossil fuel combustion sources." (p. 18)

[360] Carbon Dioxide Removal (CDR); Carbon Capture and Storage, Carbon Capture and Sequestration (CCS); Carbon Capture and Utilization (CCU); Carbon Capture and Recycling (CCR).

atmospheric carbon dioxide concentration to some extent, and (ii) the storage location and the transport of the 'captured' carbon dioxide, if the place of storage is beyond the national jurisdiction of the country where the source of these emissions is located.

- The *Kyoto Protocol* provides for 'carbon storage technologies' [UNFCCC/KP, 1997: Art. 2.1], which allow for the offsetting of some of anthropogenic carbon dioxide emissions, while encouraging their application in developed countries.[361] This includes carbon dioxide sequestered for geological storage, the climate protection issues associated with which were thoroughly analyzed by experts of the Intergovernmental Panel on Climate Change [IPCC, 2005]. In 2006, the IPCC working group that was developing the methodology for greenhouse gas emission accounting clarified how the use of this technology should be taken into account [IPCC, 2006]. The 2015 *Paris Agreement* did not detail emission reduction methods, despite some negotiating parties asking for the insertion of a reference to 'carbon removal' options for curbing the increase in the atmospheric carbon dioxide concentration [Haszeldine et al., 2018].
- The legal possibility of storing carbon dioxide in subsea geological structures was also opened up by the amendments of the *London Protocol on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* [LC, 1972; LC/LP, 1996] and the *Convention for the Protection of the Marine Environment of the North-East Atlantic* (the *OSPAR Convention*) [LC, 1972; LC/LP, 1996; [OSPAR, 1992; OSPAR, 2010]. However, according to the latter, the placement of this gas in the water column or on the seabed – which is technologically possible – was prohibited. In the European Union, it was previously proposed to regulate this solution by amending the directive on landfills [Zakkour, 2007]; however, this proposal was eventually rejected, and a separate piece of legislation was prepared (the CCS Directive). At the same time, the separation, transport and geological storage of carbon dioxide were excluded from the scope of the directives introduced to address waste and waste transport – at least in a legal sense.
- Although no serious objections were raised regarding the reinjection of hydrogen sulfide into geological formations, both supporters and opponents of carbon dioxide capture, storage, and/or utilization as part of climate policies have emerged. The IPCC was 'cautious' about this issue, and supporters also drew analogies with the desulfurization procedure (although the storage of the separated sulfur from flue gas was unnecessary because an efficient method was available for its use) [IPCC, 2018[362]; van Ewijk & McDowall, 2020]. Those who raise doubts about the process cite the considerable risks posed by carbon sequestration and storage technologies, in addition to the significantly greater effectiveness of other procedures [Sgouridis et al., 2019]. Some experts consider it impossible to halt the increase in atmospheric carbon dioxide without the use of the aforementioned technologies. In contrast, others doubt the viability of this approach and emphasize prevention over 'end-of-pipe' solutions.

[361] The author of this book was the chairman of the international body (SBSTA) that prepared the decision mentioned here between 1995 and 1997, when an agreement was reached regarding the 'CO_2 removal' procedures that CCS projects should be excluded from the Clean Development Mechanism (CDM). In 2011, the decision was overturned, but various conditions were specified for providing such support for developing countries (COP17, Durban).

[362] "The energy system transition that would be required to limit global warming to 1.5°C above pre-industrial conditions is underway in many sectors and regions around the world […]. The political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies has improved dramatically over the past few years, while that of nuclear energy and carbon dioxide capture and storage (CCS) in the electricity sector have not shown similar improvements." (p. 315)

2.5.3. Hazardous pollution and ecosystems

> The rapid loss of biological diversity, or, in a broader sense, the ecological crisis, is closely intertwined with increasing global pollution, alongside other anthropogenic drivers. The recent assessment report on biodiversity highlighted that pollution is one of the direct drivers of the harmful impacts on nature [IPBES, 2019].[363]

The widespread harmful effects of environmental pollution on ecosystems began to be more thoroughly assessed and addressed by researchers from the 1960s onwards.

- Rachel Carson not only pointed out the harmful effects of DDT pollution on the biosphere in her famous book, but like other scientists, including Garrett Hardin and Michel Batisse, drew attention to the danger of the release of increasing amounts of synthetic chemicals into the environment [Carson, 1962; Hardin, 1968; Batisse, 1969].
- Barbara Ward and René Dubos also projected the potential consequences of this process, referring to the main drivers of growing pollution: "our sudden vast accelerations – in numbers, in the use of energy and new materials, in urbanization, in consumptive ideals, in consequent pollution – have set technological man on a course which could alter dangerously, and perhaps irreversibly, the natural systems of this planet upon which his biological survival depends." [Ward & Dubos, 1972: p. 46]
- UNESCO launched its 'Man and Biosphere' program in 1971, and waste disposal was indicated as one important component of the pressures on the natural environment [UNESCO, 1971: p. 11]. The IUCN's *World Conservation Strategy* referred to such contaminants (from domestic, agricultural, industrial, and mining activities) in the context of threats to genetic diversity and as one of the serious factors contributing to habitat destruction [IUCN, 1980: Ch. 3]. Likewise, the adverse impacts of pollutants and most critical waste types on natural systems were highlighted in the *UN World Charter for Nature*, adopted by the General Assembly of the UN: "12. Discharge of pollutants into natural systems shall be avoided and: (a) Where this is not feasible, such pollutants shall be treated at the source, using the best practicable means available; (b) Special precautions shall be taken to prevent discharge of radioactive or toxic wastes." [UN, 1982: p. 4]
- A decade later, IUCN, UNEP, and WWF formulated an even clearer position on the harmful consequences of increasing pollutant emissions and the recommended actions in their joint strategy *Caring for the Earth* [IUCN-UNEP-WWF, 1991].

International agreements on nature conservation and biodiversity, as well as the strategic policy frameworks related to their implementation, have addressed the harms resulting from increasing environmental releases of pollutants, including hazardous substances and waste. Furthermore, they have defined relevant prevention and mitigation policies and measures.

- The 1992 *Convention on Biological Diversity* only denoted in general terms the human-induced reduction of biodiversity: "The Contracting Parties, […] Concerned that biological diversity is being significantly reduced by certain human activities" and "Each Contracting Party shall […] (c) Identify processes and categories of activities which have or are likely to have significant adverse impacts on conservation and sustainable use of biological diversity" [CBD, 1992: Preamble and Art. 7]. The strategy approved in 2010 by the Parties, along with the subsequent new framework program, included a target specifically for reducing the negative impacts caused by pollution: "Reduce pollution risks and the negative impact of pollution from all sources by 2030, to levels that are not harmful to biodiversity and ecosystem functions and services,

[363] "The rate of global change in nature during the past 50 years is unprecedented in human history. The direct drivers of change in nature with the largest global impact have been (starting with those with most impact): changes in land and sea use; direct exploitation of organisms; climate change; pollution; and invasion of alien species."

considering cumulative effects, […] (b) by reducing the overall risk from pesticides and highly hazardous chemicals by at least half …" [CBD/GBF, 2022: Target 7]. Clearly, such substances include persistent organic pollutants and toxic heavy metals. According to the international conventions dealing with them and their releases into the environment (*Stockholm Convention* and *Minamata Convention*), human health and the natural environment (ecosystems) should be protected from their harmful influences [SC, 2001[364]; MCM, 2013[365]]. (The use, harmful effects, and control of these hazardous substances are discussed in depth in Section 2.2 above and Chapter 1.)

- Pollutants that are dangerous to the marine environment and its ecosystems may be derived from both sea-based and land-based activities, and the respective agreements and programs aim to protect human health and the natural environment from their potential adverse implications. These issues and the necessary responses were dealt with as early as 1982 by the *United Nations Convention on the Law of the Sea* [UNCLOS, 1982],[366] then, much more concretely, in the 1995 *Agreement on Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks* [UNFSA, 1995][367] and the 1997 *Protocol to the International Convention for the Prevention of Pollution from Ships* (MARPOL, 1973/1978). The latter highlighted the need to prevent harmful substances from entering the marine environment, which are "liable to create hazards to human health, to harm living resources and marine life …", detailing in particular the provisions aimed at preventing oil pollution and the release of noxious liquid substances [MARPOL/MP, 1997]. Oil pollution is especially harmful to marine living organisms [Varga, 2009].[368]
- Cruise ships can also cause substantial damage to marine ecosystems if their bunker oil or ballast water is released into the sea. In order to prevent these hazards, international agreements have been adopted, namely, the *International Convention on Civil Liability for Bunker Oil Pollution Damage* (2001) and the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (2004).
- Waste, microplastics, and various toxic substances that enter and accumulate in the sea are seriously damaging marine and coastal wildlife. Resolutions by Parties to nature conservation conventions such as the *Convention on Biological Diversity* and the *Convention on the Conservation of Migratory Species of Wild Animals* also aimed at reducing these dangerous effects (CBD, 2016; CMS, 2011).[369]

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[364] The Parties to this Convention, "Determined to protect human health and the environment from the harmful impacts of persistent organic pollutants" (Preamble).

[365] The Parties to this Convention, "Recognizing that mercury is a chemical of global concern owing to its long-range atmospheric transport, its persistence in the environment once anthropogenically introduced, its ability to bioaccumulate in ecosystems and its significant negative effects on human health and the environment, […]. The objective of this Convention is to protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds." (Preamble, Art. 1).

[366] Article 194: "States shall take all measures necessary to prevent, reduce and control pollution of the marine environment"; Article 196(1): "States shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto".

[367] Article 5: "In order to conserve and manage straddling fish stocks and highly migratory fish stocks, coastal States and States fishing on the high seas shall, in giving effect to their duty to cooperate in accordance with the Convention: […] (f) minimize pollution, waste, discards […] (g) protect biodiversity in the marine environment".

[368] The essence of the injurious mechanism in the case of oil contamination is that the "oil layer spreading on the surface of the water forms a barrier between the water and the air, thereby preventing the oxygen in the air from dissolving in the water. The dissolved oxygen content of the water begins to decrease, and soon the death of living organisms begins. […] With the large-scale disappearance of algae, plankton and seaweed, the food chain is interrupted, and the negative processes can have a critical impact on the fish population." (p. 218)

[369] CBD, 2016: Addressing impacts of marine debris and anthropogenic underwater noise on marine and coastal biodiversity. CBD/COP/DEC/XIII/10; CMS, 2011: Marine Debris. UNEP/CMS/Resolution 10.4.

- As regards the marine pollution from land-based activities, a comprehensive international action program was approved that addressed (long before the relevant conventions were drafted) the problems of persistent organic pollutants, mercury pollution (besides other heavy metals) and plastics, moreover, radioactive pollutants, oil pollution, etc., to eliminate or at least reduce the discharges of these substances threatening the marine and coastal environment [UNEP/GPA-LbA, 1995].[370]
- The latest development in this area is the adoption of the convention on conservation of biodiversity in international marine areas (i.e., those beyond national jurisdiction) in 2023 that, in particular, determined measures against the harms caused by pollution "(c) Protect, preserve, restore and maintain biological diversity and ecosystems, including with a view to enhancing their productivity and health, and strengthen resilience to stressors, including those related to climate change, ocean acidification and marine pollution" [UNCLOS/BBNJ, 2023: Art. 17]. Obviously, this treaty reflects the concept of the 'triple planetary crisis' and, as part of this, the need to protect the integrity of ocean ecosystems and preserve marine biodiversity from the pollution that threatens it.

* * *

The aforementioned international policy and legal instruments included increasingly strict provisions aimed at the gradual prevention or reduction of the harmful influences of pollutants, hazardous chemicals, and wastes on the climate and ecosystems.

- The negative tendencies concerning ecosystems and biodiversity, that is, the intensification of the 'ecological crisis' in the sense described above, have not (yet) been curbed [IPBES, 2019[371]; CBD/GBO, 2020[372]]. Anthropogenic greenhouse gas emissions, including those from waste-related sources, are increasing. Specifically, higher emission levels from solid and liquid wastes have been detected, despite the "sizeable opportunity for reducing [these] emissions" [UNEP/EGR, 2024: pp. 7, 58].
- According to the UNEP's most recent assessment report, "Indiscriminate waste disposal practices can introduce hazardous chemicals into soil, water bodies and the air, causing long-term, potentially irreversible damage to local flora and fauna, negatively impacting biodiversity, harming entire ecosystems, and entering the human food chain. […] Pollution from chemicals and waste is a major driver of biodiversity and ecosystem change, particularly in freshwater and marine habitats […]. The three scenarios explored in this report underscore that if change does not happen at speed and scale, humanity will face unmanageable quantities of waste with potentially irreversible impacts on biodiversity, human health and climate change." [UNEP/GWMO, 2024: pp. 12, 47, 77].

2.6. THE OVERARCHING SUSTAINABILITY APPROACH TO THE GLOBAL POLLUTION PROBLEM

In addition to international agreements and policy instruments that target the prevention/reduction of the generation, environmental releases and harmful effects of pollutants, hazardous chemicals and wastes (addressing one or another specific issue, such as the persistent organic pollutants, the transboundary movement of hazardous

[370] Global Programme of Action for the Protection of the Marine Environment from Land-based Activities.

[371] (B3) "Many types of pollution, as well as invasive alien species, are increasing, with negative impacts for nature. Although global trends are mixed, air, water and soil pollution have continued to increase in some areas. Marine plastic pollution in particular has increased tenfold since 1980".

[372] "Humanity stands at a crossroads with regard to the legacy it leaves to future generations. Biodiversity is declining at an unprecedented rate, and the pressures driving this decline are intensifying." (p. 8)

wastes, or the mercury-related problematic), comprehensive programs have also been developed. These, to some extent, encompass the entire scope of this broad topic, along with other global-level socioeconomic and related environmental processes. These are of great importance, as they take into account the broader context ('synergies'), including the common drivers of the various adverse phenomena that increase the disharmony between nature and society. These comprehensive concepts-based international policy instruments include the global sustainable development program(s), the sustainable consumption and production framework(s), green/circular economic development programs, and the complex (sustainable) chemical and waste management frameworks, all of which are closely interrelated.

2.6.1. No sustainable development without overcoming the pollution crisis

Goals and actions formulated to manage environmental releases and harmful effects of pollutants, including hazardous chemicals and waste, have become an integral part of sustainable development programs. The creation of global sustainability programs has a history spanning several decades. As a result of a relatively lengthy preparatory process initiated on the basis of the 1989 UN resolutions, the global sustainable development program approved in 1992 detailed the pollution-related tasks in separate chapters, then the UN member states defined even more concrete common goals and means of international collaboration to target this very broad problematic in 2015.

The global sustainable development program *Agenda 21* was adopted by the United Nations Conference on Environment and Development (UNCED) in 1992 and included the comprehensive consideration of (i) human activities producing inter alia substantial amounts of pollutants and releasing hazardous chemicals and wastes into the environment, and (ii) the subsequent serious harms to human health and the natural environment (as a 'feedback effect' of those activities). It was also made clear that without properly addressing these adverse human-environment interactions, overall sustainability objectives cannot be achieved.

- The UN resolutions of 1989 provided indications about numerous issues which the projected summit and its expected outcome document should deal with in an integrated manner, including the broad problematic of pollution. "The General Assembly, […] 12. Affirms that […] the following environmental issues […] are among those of major concern in maintaining the quality of the Earth's environment and especially in achieving environmentally sound and sustainable development in all countries: […] (g) Environmentally sound management of wastes, particularly hazardous wastes, and of toxic chemicals" (UN Resolution No. 44/228, 1989). "The General Assembly, […] Recognizing that the United Nations Conference on Environment and Development, to be held in 1992, is a unique opportunity for all nations to address environmental and development issues in an integrated manner and to mobilize their political will to solve environmental problems through international co-operation" (UN Resolution No. 44/229, 1989).
- Given such antecedents in terms of the 'guidance' of the abovementioned UN resolutions, it was almost self-evident that several chapters of the world program on sustainable development adopted at the 1992 UN 'Earth Summit' would deal with the globalizing problem of chemicals, pollutants, and wastes, as well as the related actions to be taken [UN, 1992]. The respective chapters covered the fields of toxic chemicals (Chapter 19), hazardous wastes (Chapter 20), solid wastes and sewage (Chapter 21), and radioactive wastes (Chapter 22). The general aims of the actions defined regarding all these segments of the global level pollution problem were the

protection of human health and the environment as integral constituents of the overall sustainable development objective.[373]

- Some specific time-bound targets were also agreed upon. They stipulated that by the year 2000, risk assessments of globally significant 'priority' chemicals and pollutants should be carried out, and national systems for their environmentally sound management introduced in all countries. Moreover, waste minimization programs should also be prepared, the amount of waste going to landfills in developed countries should no longer increase, and developing countries should strive to realize these goals (in line with this, there should be sufficient capacity for efficient waste reuse and recycling), etc. By 2025, the disposal of all sewage, wastewater, and solid waste (in conformity with national or international environmental quality guidelines) and the effective management of urban waste should be achieved. The program addressed sustainability criteria for all key economic sectors, including pollution-related ones (e.g., developing and promoting less polluting forms of energy, less polluting transport technologies, and increasing the efficiency of the production and consumption of resources and materials by industry).
- In addition to the general goal of reducing the harmful effects of various pollutants on human health and the environment associated with the above-mentioned topics, a separate chapter[374] was dedicated to protecting human health in this sustainable development program.[375] Within its framework, the main environmental influences and actions that threaten health were formulated, including tasks related to pollutants, hazardous chemicals, and waste, with regard to their health risks.
- This agenda addressed these 'unsustainable' issues not only at the level of environmental pressures and their harmful effects, but also clarified their root causes ('drivers'): first of all, the unsustainable patterns of production and consumption, which changes are required for optimization of resource use, minimization of waste and prevention of pollution [UN, 1992: 4.15, 19.44, 21.4].

The reinforcement of objectives and further concretization of the goals and necessary actions. After 1992, some progress was made in numerous developed countries and several developing ones in the areas of reducing environmental pollution and sustainable chemical and waste management; however, this was hardly demonstrable at the global level. Therefore, the previously set objectives, targets, and actions were reinforced and/or refined and repeatedly strengthened at subsequent sustainable development forums.

- Despite political commitments ('promises') concerning sustainable development, the international community has fallen far short of achieving most of the goals agreed in the early 1990s, as shown by the fact that environmental releases of pollutants and waste have continued to increase globally. For this reason, unsustainable processes and the necessary actions were put back on the agenda at the subsequent high-level UN forums. As early as the 1997 meeting ('Rio+5' conference), doubts were raised due to the initial signs of failure in implementing the *Agenda 21* program adopted in 1992: "[W]e are deeply concerned that the overall trends with respect to sustainable development are worse today than they were in 1992. We emphasize that

[373] (19.1) "[E]nsure the environmentally sound management of toxic chemicals, within the principles of sustainable development". (20.1) "Effective control of the generation, storage, treatment, recycling and reuse, transport, recovery and disposal of hazardous wastes is of paramount importance for proper health, environmental protection and natural resource management, and sustainable development." (21.1) "[E]nvironmentally sound management of wastes was among the environmental issues of major concern in maintaining the quality of the Earth's environment and especially in achieving environmentally sound and sustainable development in all countries." (22.3.) "The objective of this programme area is to ensure that radioactive wastes are safely managed, transported, stored and disposed of, with a view to protecting human health and the environment".

[374] Ch. 6. (E.) Reducing health risks from environmental pollution and hazards: (6.39.) "There have been notable improvements in some countries, but deterioration of the environment continues. […] Pollution control and health protection measures have often not kept pace with economic development."

[375] Issues related to the protection of the natural environment and biodiversity were discussed above (Section 2.5).

the implementation of Agenda 21 in a comprehensive manner remains vitally important and is more urgent now than ever" [UN, 1997: par. 4]. These negative findings were also applicable to trends related to the natural environment and its contamination.[376] Essentially, the same thing happened in 2002 at the World Summit on Sustainable Development, and, for this reason, a complex implementation plan[377] was adopted at that time, which also strengthened the targets for the abatement of the global pollution problematic and addressed its socioeconomic drivers and harmful effects. It also specified how international cooperation in this area should be strengthened [UN, 2002].[378] This summit raised the need to establish an international policy framework for sustainable consumption and production.[379]

- High-level political representatives from countries around the world met again in 2012 and recommitted themselves to sustainable development [UN, 2012].[380] It was found that there was a significant gap in respect of the previously agreed targets, including for chemicals and waste: "We recognize that the sound management of chemicals is crucial for the protection of human health and the environment. […] We also reaffirm our commitment to an approach for the sound management of chemicals and waste, at all levels, […] and encourage further progress across countries and regions in order to fill the gaps in the implementation of commitments." (par. 213) For this reason, they considered an integrated and comprehensive approach to dealing with the wide-ranging, unsustainable processes to be more important than before. This is also why an agreement was finally reached to address the unsustainable consumption and production patterns, which were considered the root causes of the former, including in relation to growing environmental problems. Furthermore, they also agreed on the significance of the green economy concept (pars. 4, 224; pars. 56-74); concerning these development concepts and programs, see the following subsections of this chapter).
- Instead of the policy directions and instruments that had been strengthened and clarified but proved insufficiently effective at implementing the overarching program approved in 1992, it was stated at various high-level conferences afterwards (such as the 2015 UN sustainable development conference) that a "new approach" was needed (UN, 2015: par. 13). This not only meant that even greater attention should be paid to the interrelations of various socioeconomic and environmental processes and the drivers of harmful problems, but also that a clearer and more specific, time-bound set of sustainable development goals and targets were defined than before in this *Agenda 2030*. This extended to the issues associated with pollutants, hazardous chemicals, and waste. Therefore, inter alia, this sustainable development program included the reconfirmation of the previously set general target that by 2020 the "environmentally sound management of chemicals and all wastes" should be achieved and a significant reduction in "their release to air, water and soil in order to minimize their adverse impacts on human health and the environment".

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[376] "Many polluting emissions, notably of toxic substances, greenhouse gases and waste volumes are continuing to increase […]. Insufficient progress has also been identified in the field of environmentally sound management and adequate control of transboundary movements of hazardous and radioactive wastes. Many countries undergoing rapid economic growth and urbanization are also experiencing increasing levels of air and water pollution, with accumulating impacts on human health". (par. 9)

[377] Johannesburg Plan of Implementation (JPoI).

[378] 22. "Prevent and minimize waste and maximize reuse, recycling […] (a) Develop waste management systems, with the highest priority placed on waste prevention and minimization, reuse and recycling, and environmentally sound disposal facilities …" 23. "Renew the commitment, as advanced in Agenda 21, to sound management of chemicals throughout their life cycle and of hazardous wastes for sustainable development as well as for the protection of human health and the environment …".

[379] The author of this book was a member of the Hungarian delegation at the three summits mentioned here.

[380] (19.) "We emphasize the need to make progress in implementing previous commitments." (20.) "In this regard, it is critical that we do not backtrack from our commitment to the outcome of the United Nations Conference on Environment and Development. We also recognize that one of the current major challenges for all countries […] is the impact from the multiple crises affecting the world today." (40.) "We call for holistic and integrated approaches to sustainable development that will guide humanity to live in harmony with nature and lead to efforts to restore the health and integrity of the Earth's ecosystem."

It was also specified that by 2030 the following targets should also be achieved: substantial reduction of "waste generation through prevention, reduction, recycling and reuse" and improvement of "water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally" [UN, 2015: pars. 12.4, 12.5, 6.3]. The same year, the *Global Waste Management Outlook* was published, underlining the close relationship between adequate waste management and the achievement of sustainable development – where under "waste" in this report was understood all "such unwanted outputs of human activity as gases, liquids and solids as well as discharges to the three environmental receiving media of air, water and land" [UNEP/GWMO, 2015].[381]

- According to the latest assessments, there is a serious backlog in the implementation of the goals approved under the *Agenda 2030* [UN/SDGR, 2024],[382] and this applies, among other things, to air pollution, freshwater pollution (although the adverse health effects of this have been somewhat reduced), and pollutants entering the marine environment. Notably, the situation regarding hazardous chemicals and waste, as well as e-waste, is particularly unfavorable.[383] From all this, the following general conclusions were drawn: "Urgent action is imperative. Addressing pressing environmental challenges and their underlying drivers and interconnections – including climate change, biodiversity loss, pollution, desertification and deforestation – demands intensified, accelerated efforts, and a comprehensive and integrated approach at local, national and global levels." (p. 38)

[381] "Waste management is a cross-cutting issue impacting on many aspects of society and the economy. […] The political case for action is significantly strengthened when waste management is viewed as an entry point to address a range of such sustainable development issues, many of which are difficult to tackle. […] So, a strong argument can be made for the strategic importance of improving waste management, insofar as actions here will contribute to progress towards a range of SDG targets. Setting and monitoring global targets for waste management will thus contribute significantly to attaining the SDGs." (pp. 21-22)

[382] "The progress assessment carried out in 2024 reveals that the world is severely off track to realize the 2030 Agenda". (p. 4)

[383] "Countries have made strides in meeting obligations under international environmental agreements on hazardous waste and other chemicals and implementing comprehensive approaches to combat environmental degradation. Patterns of unsustainable consumption and production persist, however. […] The rapid growth of global e-waste remains largely unaddressed, with only 22 per cent collected and managed sustainably." (p. 32)

2.6.2. Managing the environmental burden from unsustainable production and consumption

The rapid expansion and diversification of production and consumption activities since the mid-20th century, along with the volume and variety of obsolete equipment, products, and material residues, have contributed to the increasing release of pollutants, hazardous chemicals, and waste into the environment. Representatives from various scientific disciplines have been studying the harmful effects of production processes and consumption habits for some time, and have suggested possible ways to change them. International cooperation between researchers in this area was institutionalized from the 1980s onwards, and evaluation reports and recommendations were prepared with their participation [e.g., UNEP/GEO, 1997[384]; SEI, 1998[385]; UN, 1999; IRP, 2010].[386] These formed the basis for policy recommendations, which included objectives and recommended activities under the heading of 'sustainable consumption and production' (SCP) in the outcome documents of international summits dealing with environmental and sustainability issues since 2002, as well as in the international framework program dedicated to this topic.

The environmental impacts of production and consumption activities have long been recognized, but they were either not considered significant or the motivation to address them was lacking. However, as rapid growth in production and consumption began to cause problems with access to the relevant natural resources (e.g., due to their gradual depletion) and/or damage to health and the environment, more and more analyses and calls to pay attention to these connections emerged.

- Several such publications have been mentioned at the beginning of this chapter, and only a few statements are quoted below from the respective essays of Vance Packard and Kenneth Boulding that illustrate the extensive environmental damage they anticipated in the 1960s.
- "*Chapter 17: Ever-Mounting Consumption?* […] There is the uncomfortably challenging point to be recognized that perhaps the United States has no acceptable alternative to ever-rising and wasteful consumption. […] An official of the United States Public Health Service warns that 'the amount of chemical junk in the air will grow astronomically as time goes by'. The rivers of the nation from which dozens of down-river towns are dependent for drinking water have become dangerously polluted with industrial wastes, household detergents, and sewage-born microscopic worms called nematodes. […] *Chapter 24: Facing the Unmet Challenges*. […] We should not overlook, either, the now poorly met challenges of reversing the shrinkage of forest lands, of conservation of the shrinking arable land, and combating the spread of pollution in both air and water." [Packard, 1960: pp. 112, 117, 183].
- "We are now in the middle of a long process of transition in the nature of the image which man has of himself and his environment. […] The closed earth of the future requires economic principles which are somewhat different from those of the open earth of the past. […] The difference between the two types of economy becomes most apparent in the attitude towards consumption. In the cowboy economy, consumption is regarded as a good thing and production likewise […]; and the success of the economy is measured by the amount of the throughput from the 'factors of production', a part of which, at any rate, is extracted from the reservoirs of raw

[384] "Cleaner, more resource-efficient production applies not only to industrial production processes, but also to agriculture, fisheries, forestry, transportation, and so on. […] Cleaner production leads to reductions of resource use and in amounts of waste and emissions generated." (pp. 134-135)

[385] "Extracting, refining, manufacturing, transporting, and ultimately disposing of materials is a major cause of pollution and waste in industrial societies. […] In order to stabilize environmental pressure as economies and populations grow, the flow of material into societies must be controlled through designing more durable products, reducing waste streams through reuse of materials, and cleaner production processes." (p. 17)

[386] In that period, the author of this book was a member of the SEI Global Scenario Group (GSG), participated in the 1997 session of UNEP, and assisted in the establishment of the International Resources Panel (IRP) in Budapest in 2007.

materials and noneconomic objects, and another part of which is output into the reservoirs of pollution. […] The essential measure of the success of the economy is not production and consumption at all […]. All these considerations add some credence to the point of view which says that we should not worry about the spaceman economy at all, and that we should just go on increasing the GNP and indeed the gross world product, or GWP, in the expectation that the problems of the future can be left to the future, that when scarcities arise, whether this is of raw materials or of pollutable reservoirs, the needs of the then present will determine the solutions of the then present …" [Boulding, 1966: pp. 1, 4-6].

- The international aspects of this problem were analyzed at an expert forum in 1971. The participants highlighted the significant differences between the socioeconomic situation of developed and developing countries, but made it clear that production processes – albeit to varying degrees – have serious environmental implications, including an increase in environmental pollution [UN, 1971].[387] This forum made recommendations for tackling the identified problems ('Control of pollution and environmental hazards', pp. 9-14).
- The 1972 UN Conference (UNCHE) primarily made recommendations for the effective international monitoring and assessment of the environmental damages stemming from various production activities, besides emphasizing the importance of the prevention/control of pollution and waste, the environmental discharge of harmful chemicals and other pollutants, and the significance of relevant activities of the specialized UN organizations (FAO, IAEA, UNESCO, UNIDO, WHO, etc.).

A dedicated international framework program aimed at changing 'unsustainable production and consumption' was finally adopted in 2012, which specified general requirements and courses of action for transitioning to sustainability in this area. The negative implications to be prevented or mitigated included adverse impacts related to the unsustainable utilization of natural resources (such as overexploitation and degradation) and environmental releases of pollutants, hazardous chemicals, and wastes. However, it took a long time from the end of the 1980s to its finalization and adoption, primarily due to the considerable differences in the situation and priorities between developed and developing countries. As a result, this document could only be prepared at the cost of major compromises.

- Comprehensive reports presented by UNEP and the UN World Commission on Environment and Development in 1987 detailed the serious social and environmental damages caused by various production and consumption patterns associated with economic development in general, and its major sectors in particular, and made specific recommendations for policies and measures to mitigate them [UNEP, 1987; WCED, 1987]. These were taken into account during the development of the global sustainable development program (Agenda 21), adopted in 1992, which emphasized that the consumption and production tendencies that had developed primarily in developed countries up to that point could not be continued. This can be considered a kind of holistic guideline for the future – as one of the statements reads: "Future patterns of agricultural and forestry development, energy use, industrialization, and human settlements can be made far less material-intensive […], and hence both more economically and environmentally efficient." (Ch. 3, par. 76) This program dedicated a separate chapter to this topic (Ch. 4), which started with the assessment that "the major cause of the continued deterioration of the global environment is the unsustainable pattern of consumption and production". Based on this, the key objectives[388] were defined according to which the transition to sustainable patterns (SCPs) should be promoted.

[387] "The processes of agricultural growth and transformation, for example, will involve the construction of reservoirs and irrigation systems, the clearing of forests, the use of fertilizers and pesticides and the establishment of new communities. These processes will certainly have environmental implications. Similarly, industrialization will result in the release of pollutants and react on the environment in a number of ways." (p. 5)

[388] "Action is needed to meet the following broad objectives: a) To promote patterns of consumption and production that reduce environmental stress and will meet the basic needs of humanity; b) To develop a better understanding of the role of consumption and how to bring about more sustainable consumption patterns." (par. 4.7)

In alignment, courses of action were defined to achieve greater resource efficiency, and reduce pollution, and minimize waste generation (pars. 4.8.-4.14., 4.18.-4.27.). The proposed activities considered most important included (i) developing a better understanding of the relationship between production and consumption, as well as their effects on the use of natural resources and the release of hazardous substances into the environment, (ii) the development of new concepts of wealth and prosperity which allow higher standards of living through changed lifestyles that and are less dependent on the Earth's finite resources and more in harmony with the its carrying capacity, and (iii) adopting an international approach towards sustainable patterns of production and consumption. Taking all these provisions into account, it was concluded that, in the follow-up to the implementation of *Agenda 21*, this topic should be given more attention.

- This issue was again on the agenda at the 2002 World Summit (WSSD), but no such program could be formulated/adopted at that time, despite the consensus about the need to transition to sustainable patterns of production and consumption [UN, 2002].[389] One of the main obstacles (mentioned above), as with many other topics, was the fact of the different situations and 'differentiated' responsibilities of certain groups of countries – of course, primarily the developed and developing countries – in relation to the unsustainable use of natural resources, increasing environmental pollution and waste production, and the harmful effects resulting from all of this.

The framework for sustainable consumption and production policies was adopted ten years later, at the 2012 United Nations Conference on Sustainable Development (UNCSD), with the stipulation that the preparation and implementation of such policy programs are voluntary [UN/10YFP, 2012].

- As a result of political compromises, only a simplified concept, vision, and the most basic elements of sustainable consumption and production could be agreed upon in the form of a *10 Year Framework of Programmes on Sustainable Consumption and Production Patterns*. However, it was made clear that only such an approach could guarantee the achievement of sustainable development, the maintenance of socioeconomic development within the carrying capacity of the environment, and a reduction in the use of hazardous substances, environmental pollution, and waste generation through the sustainable use of natural resources.[390] Special emphasis was placed on ensuring that this framework would contribute to strengthening coherence with sustainable development commitments and international environmental agreements, promoting scientific and technical cooperation, collaboration with all relevant stakeholders, and raising awareness of the importance of pursuing SCP. Recommendations were also made regarding the inclusion of other essential areas in such programs (consumer information, sustainable lifestyles and education, sustainable public procurement, sustainable buildings and construction, and sustainable tourism). UNEP was tasked with coordinating and assisting in the implementation of this *Framework*, for which purpose an extensive international stakeholder network (the One Planet Network) was also established.
- The sustainable development program adopted in 2015 – *Agenda 2030* – not only had the implementation of this program framework (10YFP)[391] as a stand-alone goal but determined some time-bound concrete targets for it [UN, 2015: targets 12.2-12.5].

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[389] "14. Fundamental changes in the way societies produce and consume are indispensable for achieving global sustainable development. All countries should promote sustainable consumption and production patterns […] 15. Encourage and promote the development of a 10-year framework of programmes in support of regional and national initiatives to accelerate the shift towards sustainable consumption and production."

[390] (1.b): "accelerate the shift towards sustainable consumption and production in order to promote social and economic development within the carrying capacity of ecosystems by addressing and, where appropriate, decoupling economic growth from environmental degradation by improving efficiency and sustainability in the use of resources and production processes and reducing resource degradation, pollution and waste." (1.c): The 10-year framework should affirm a common vision that: "(v) Reduces the use of hazardous materials and toxic chemicals and the generation of wastes, such as non-biodegradable materials and the emission of pollutants …"

[391] (12.1) Implement the 10-year framework of programmes on sustainable consumption and production.

- According to the progress report published before the end of the ten-year period, extensive international cooperation has developed and programs have been created in many places around the world to improve the resource efficiency of production and consumption and reduce environmental damage, but still a "transformational shift is required to achieve sustainable development driven by resource efficient, low carbon, non-polluting consumption and production patterns. […] Much more needs to be done to mainstream sustainable consumption and production policies, approaches and solutions …" [UN/10YFP, 2021: pars. 15, 17]. However, from the perspective of *Agenda 2030*, this issue remained of key importance, along with the science-policy interface and international stakeholder collaboration that had been established and proved particularly useful. Therefore, the UN General Assembly decided to sustain the activities carried out within this *Framework* until the end of 2030 [UN, 2021b].[392] However, much more effective implementation will be needed, because as stated by the 2024 UN report on the Sustainable Development Goals: "Countries have made strides in meeting obligations under international environmental agreements on hazardous waste and other chemicals and implementing comprehensive approaches to combat environmental degradation. Patterns of unsustainable consumption and production persist, however." [UN/SDGR, 2024: p. 32 on Goal 12]

[392] "The General Assembly, […] encourages further efforts aimed at strengthening international cooperation to address gaps in the implementation of the 2030 Agenda for Sustainable Development; acknowledges, in this regard, that sustainable consumption and production practices can be cost-efficient and effective ways to achieve economic development, reduce environmental impacts and advance human well-being […] decides to extend the mandate of the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns until 31 December 2030, and encourages the implementation of the Framework of Programmes, in accordance with target 12.1 of Goal 12". (pars. 6, 7, 9)

2.6.3. What should the economy be like: green and/or circular?

> Since the 1990s, calls for a transition to a "green economy" and subsequently to a "circular economy" have gained momentum. Their benefits have been extensively studied by many experts. Even if not using these terms, concepts with such content – i.e., involving a new approach to managing natural resources, environmental pollution, and waste – are much older, as are their scientific foundations. First of all, these include the extended modeling of the material and waste flows between the economy and the environment [Victor, 1972],[393] moreover, some environmental and ecological economic studies may also be mentioned [Pearce et al., 1989; Costanza et al., 1991; Costanza, 1991[394]; Pearce, 1992]. Hungarian researchers have also articulated the need for a shift in the consideration of environmental aspects in economic activities [Kerekes, 1998; Simai, 2001]. While these research trends have strengthened and broadened, previous UN summits (in 1992, 1997, and 2002) have not given sufficient emphasis to delineating what the economic dimension of sustainable development should be.[395]

Interest in the 'green economy' shift, including its ways and means, has revived strongly since the economic crisis of 2007-2009.

- The shift to a 'green economy' has been driven not only by the previously proposed and applied 'green solutions' (e.g., green taxes or environmental taxes), but more importantly, by the implementation of a comprehensive system of innovative instruments [Barbier, 2010; Kiss, 2010].
- The possibility of a systemic 'green transition' has also been assessed at the international level [UNSG, 2010; UNIDO, 2010; UNEP, 2011[396]]. In contrast, other institutions have advocated for the primacy of economic considerations and supported only 'green growth', i.e., the revival of economic growth, albeit with some degree of 'greening' [OECD, 2009[397]; WB, 2012[398]].
- These antecedents foretold that the central theme of the 2012 UN Conference on Sustainable Development would be the 'green economy'. The expert basis for this discussion was established by the aforementioned UNEP analysis, which detailed the primary tasks of the transition, including policies and tools that would lead to a reduction in pollution and waste generation, and

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[393] "[T]raditional approaches are of limited use in analysing the output of wastes received by the environment, they are even less helpful in the study of the flow of inputs from the environment to the economy. What is required is a methodology that explicitly recognizes that the production of economic commodities requires flows of materials both to and from the environment. […] Some aspects of this rearrangement in the course of economic activity are desirable: the production of goods and services; and some are undesirable: the production of wastes." (p. 18)

[394] "Better understanding of ecological systems and how they function and maintain themselves can yield insights into designing and managing sustainable economic systems. For example, there is no 'pollution' in climax ecosystems; all waste and by-products are recycled and used somewhere in the system or harmlessly dissipated. A characteristic of sustainable economic systems should also be a similar 'closing the cycle' by finding economic uses and recycling 'pollution', rather than simply storing it, exporting it, diluting it, or changing its state". (p. 337)

[395] As a member of the Hungarian negotiating delegation, the author of this book participated in these UN conferences at which numerous scientific and civil organizations, besides the EU representatives, for example, considered it important to discuss the 'economic dimension' of sustainable development and reflect this in the outcome document.

[396] "UNEP defines a green economy as one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. […] In a green economy, growth in income and employment should be driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services. […] The concept of a 'green economy' does not replace sustainable development, but there is now a growing recognition that achieving sustainability rests almost entirely on getting the economy right." (p. 1)

[397] "It is important that the measures governments are taking now to address the economic crisis are designed so that they support […] sustainable long-term, environmentally friendly growth in the future." (p. 7)

[398] "We argue that what is needed is green growth – that is, growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts […]. Greening growth need not entail slower growth and is affordable." (pp. 2, 25)

presented the related economic and employment benefits [UNEP, 2011]. During the preparations for the conference, it was difficult to reach an agreement, again primarily due to the different situations and interests of developed and developing countries [Faragó, 2012].

- Finally, the outcome document adopted by the conference [UN, 2012], in its chapter entitled *Green economy in the context of sustainable development and poverty eradication*, listed some of the key objectives of such an economy besides providing a lengthy list of conditions to be taken into account in the formulation and implementation of such national programs (par. 58: (a)-(p)). In line with the former, such a green economy "should contribute to eradicating poverty as well as sustained economic growth, enhancing social inclusion, improving human welfare and creating opportunities for employment and decent work for all, while maintaining the healthy functioning of the Earth's ecosystems […], will enhance our ability to manage natural resources sustainably and with lower negative environmental impacts, increase resource efficiency and reduce waste" (pars. 56, 60). This chapter was intended to be a kind of guideline for countries that voluntarily intended to introduce or further develop such an economic policy framework, rather than a global green economy development program.
- This system of objectives, instruments, and conditions was soon subject to profound criticism because it merely represented the apparent 'greening' of economic growth, considered unsustainable by many [e.g., Jacobs, 2013].[399] This might be partly why the new sustainable development agenda no longer referred to the 'green economy' at all when it set out the main requirements for "sustained and sustainable economic growth" [UN, 2015: Goal 8]. Indeed, only one of its ten targets referred to the environmental criteria – the one that recalled the "10-year framework of programmes on sustainable consumption and production" approved in 2012, as well.[400]
- So, the 2012 UN conference officially only devoted attention to the topic of the 'green economy' and formulated its compromise position made acceptable by consensus in the outcome document (*The Future We Want*), and only acknowledged with approval the above-mentioned SCP framework (the product of the multi-stakeholder Marrakech Process, 2003–2011). However, the further development, refinement, and implementation of the 'green economy' concept continued, and its coordination is being carried out in cooperation with several specialized UN organizations (PAGE), as well as promoted by an international institution that has since been established (GGGI).[401]

The 'circular economy' model also had theoretical antecedents, but its actual application at the national and international level has only begun to gain ground in recent decades. The goals and courses of action of this approach have expanded beyond the previously and narrowly interpreted concepts of the 'green economy' (or only 'greening' the economy) and can thus more effectively promote the sustainable use of natural resources and reduce environmental pollution and waste flows.

- The 'output dimension' of this concept (i.e., that associated with the proposals that considered pollution and waste reduction to be necessary and possible) gradually progressed to the formulation of the principle of 'closed-loop material flow' [Boulding, 1966; Pearce & Turner, 1990]. The concept of the 'circular economy' (CircE) has other predecessors, such as 'industrial ecology', which also prioritized pollution and waste minimization. Additionally, there are theories

[399] "As these different forms of the green growth argument have been articulated and debated in the period since 2008, each has found supporters and critics among governments and international institutions, and within the wider academic and policy communities. It is clear that in most countries the dominant economic view remains that the case for green growth is unproven: strong environmental policy continues to be seen largely as a drag on growth rather than a driver of it". (p. 208)

[400] (8.4) "Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead".

[401] Partnership for Action on Green Economy (PAGE) (UNEP, ILO, UNDP, UNIDO, UNITAR); Global Green Growth Institute (GGGI).

like ‘cradle to cradle’, the ‘performance economy’, and ‘permaculture’, among others [Ausubel, 1992[402]; McDonough & Braungart, 2002; Stahel 2006[403]].

- The implementation of the CircE model into practice has also begun: for example, in the People’s Republic of China, with a project from 2002, and then supported by a law[404]; in Germany somewhat later, but finally enacted into law there as well; in France, through an institute that promotes the introduction of this zero-waste concept; and in Hungary, through a foundation with the same mission.[405]
- Preparation for the 2012 UN sustainable development conference (UNCSD) contributed to the support of this economic model to the extent that many saw its implementation as a way to ensure much more efficient resource management and a solution to the pollution problem [Preston, 2012[406]; UNEP, 2011[407]; EMF, 2012[408]]. After this, the spread and further development of the CircE theory accelerated [d’Amato et al., 2017; Wautelet, 2018; Fogarassy & Horváth, 2018; Pomázi & Szabó, 2018; Rácz, 2018; Nagy et al., 2021[409]].
- International cooperation has also expanded: with the adoption of the ‘Zero Waste’ program and the ‘Circular Economy Action Plan’ within the EU (2014, 2015, 2020), with the extension of the activities of some UN institutions in this direction (UNEP, UNIDO, UNCTAD, UNECE) and the actions of international networks (GACERE, PACE, WCEF).[410]
- While criticism and development of the CircE theory continues [e.g., Giampietro, 2019[411]; Andrade et al., 2021; Valverde & Avilés-Palacios, 2021], at least at a global level, the application of this model has not been groundbreaking, and thus, the world has not come much closer to the sustainable use of natural resources and a significant reduction in the burden on the planetary environment created by a wide variety of pollutants, which fundamental objectives were and

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[402] “This multiplication of needs means that we need a science and industry for a small planet. Industrial ecology can contribute both understanding and solutions. If the current ratios of emissions, pollution, and waste creation to production and consumption are maintained, the environmental problems are certainly going to become worse.” (p. 880)

[403] “Why the shift to selling performance in the Functional Service Economy? […] its economic actors can profitably exploit sufficiency solutions as well as loss and waste prevention opportunities.” (p. 86)

[404] Circular Economy Promotion Law of the People’s Republic of China (2008).

[405] Circular Economy Act (Kreislaufwirtschaftsgesetz); L’institut de l’économie circulaire; Foundation for Circ. Economy (founded by Máté Kriza).

[406] “In the run-up to the United Nations Conference on Sustainable Development (Rio+20) in June 2012, there has been a renewed focus on pursuing meaningful action to reduce resource and environmental pressures. […] Governments in crucial countries have already introduced policies and strategies on resource efficiency – driven by concerns over energy and resource security, but also by escalating problems in managing waste and pollution.” (pp. 2, 13)

[407] “1.3 A vision for the waste sector. The long-term vision for the waste sector is to establish a circular global economy in which the use of materials and generation of waste are minimised, any unavoidable waste recycled or remanufactured, and any remaining waste treated in a way that causes least damage to the environment and human health or even creating additional value by recovering energy from waste.” (p. 295)

[408] “A circular economy […] replaces the ‘end-of-life’ concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models.” (p. 7)

[409] “In the circular economy built on new foundations, unlike the traditionally interpreted ‘linear’ model, no waste is generated, as today’s products are the raw materials for later ones, resulting in a closed loop, i.e. a cycle.” (p. 1110)

[410] Global Alliance on Circular Economy and Resource Efficiency (GACERE); Platform for Accelerating the Circular Economy (PACE); World Circular Economy Forum (WCEF)

[411] “[T]he circular economy ‘business model’ provides no theoretical framework to identify targets and indicators for its implementation. Which flows should be accounted for and how (in relation to which transformations) when generating an integrated set of targets monitoring the implementation of the circularity of ‘the economy’? The claimed decoupling of economic growth from natural resource use is only related to targets for increasing the level of ‘reusing and recycling’. It is unclear why estimates of the quantities of recycled wastes and the amount of material recycled from products arrived at their end-of-life should be useful indicators to study green economic growth. Why should an economy grow by shifting resource investments from producing and consuming goods and services to recycling wastes and used materials? The new business model proposed for the circular economy does not provide a credible theoretical discussion of the growth issue.” (p. 154)

remain those of 'circular economy' [EPRS, 2023[412]; UNEP, 2024]. According to a recent assessment report on this 'circularity': "In the material flow accounting framework for 2019, the tally for waste and emissions is significant. […] To push the circularity rate beyond its current potential, there must be a fundamental restructuring of the global production and consumption system. […] The redesign of production and consumption systems is increasingly viewed as a crucial aspect of the circular economy because it encompasses more than just resource recovery and recycling." [IRP, 2024: p. 25]

2.7. CONCLUSIONS AND LESSONS LEARNED

International cooperation on pollutants, hazardous chemicals, and waste and the need for further efforts

> "By 2030, the world is expected to generate 2.59 billion tonnes of waste annually […]. By 2050, waste generation across the world is expected to reach 3.40 billion tonnes".
>
> *Silpa Kaza et al., 2018*[413]

The pollution problem has become global in recent decades. International agreements regarding injurious pollutants, hazardous chemicals, and waste have been established, with respective goals also integrated into environmental policy and sustainability programs. Based on the detailed overview of the scientific exploration and policy cooperation process concerning these issues that is presented above, some general conclusions and lessons may be drawn.

Natural resource and waste management have improved in some regions thanks to relevant regulatory and policy instruments, following a better understanding of the adverse effects of resource degradation, increasing pollution, the inappropriate management of chemicals and waste, and recognition of the multiple benefits of mitigating/preventing these problems. Overall, however, unsustainable resource management and environmental contamination remain a serious concern.

- Growing pollution, waste production, and their diverse and perilous consequences have become shared concerns worldwide. The most obvious and visible signs of this have been harmful pollutants transported in the atmosphere and water bodies, and even reaching areas distant from their sources, including those outside national jurisdiction [e.g., Dabrowska et al., 2021].[414]
- Accelerated socioeconomic processes, such as the global population 'explosion', the expansion of production and consumption, and urbanization, have not only led to the often-wasteful use of raw materials and other natural resources, but also to environmental damage reaching a planetary scale.
- The relationship of societies to the natural environment cannot continue in the current way, because the resource depletion and release of pollutants due to human activities are gradually destroying the entire environment itself, clearly showing how dangerous the route is that the

[412] "Therefore, while the circular economy is very important, the recycling potential is limited. Furthermore, innovation may be an important driver of growth and can also contribute to solving environmental problems; however, insufficient technological change, such as deployment and replacement of polluting technologies and processes, slows decoupling." (p. 26)

[413] These assessments were made for municipal solid waste under the BAU scenario. The global amount of such waste was 2.01 billion tons in 2016. Consequently, if the growth trends of this waste generation do not change, the amount will be 70% higher in 2050, according to these experts. (p. 24)

[414] "Possible scenarios indicate that without decisive action to protect marine ecosystems, one tonne of plastic will correspond to every 3 tonnes of fish by 2025, and by 2050, we can expect more plastic than fish (by weight)." (p. 4)

present mode of 'development' is heading in [Fischer-Kowalski & Rotmans, 2009[415]; Krausmann et al., 2018[416]].

- In the course of the emergence and development of comprehensive international cooperation on these issues, developed and developing countries have been pitted against each other based on their different situations and responsibilities in relation to these threats. This occurred, inter alia, at the 1972 and 2012 UN conferences (held in Stockholm and Rio de Janeiro, respectively), where developed countries prioritized reducing environmental pollution, while the priorities of developing countries were combating extreme poverty and increasing the level of support for solving their social and environmental problems. In 1972, Prime Minister of India, Indira Gandhi, made this clear,[417] and in the run-up to the 2012 conference, the Chinese negotiating delegation communicated the developing world's position on the 'green economy' in a similar spirit.[418]
- This slowly changing North-South world divide – especially in terms of the differing situations of the 'First World' and the 'Third World' – was and remains one of the fundamental barriers to the greater effectiveness of international sustainability and development programs that also address common environmental hazards. Consequently, only by thoroughly taking into account the nations' very different situations, responsibilities, and opportunities will there be any chance of significant progress in solving this environmental and many other global crises.

Recognizing the injurious effects of toxic chemicals and hazardous waste has led to agreements and programs with specific goals, provisions, and tools, including those that would also protect international areas and their ecosystems from such contamination. Besides the above-mentioned reasons, due to shortcomings in the implementation of such international instruments, the environmental and other related 'unsustainability' affairs they address have not yet been alleviated to a significant extent at the global level. This is indicated by the still large-scale release of substances dangerous to human health and the environment, the continued illegal international transport of wastes, and the accumulation of debris at sea and in outer space. Without more effective interventions, the environmental burden of such pollutants – including toxic chemicals, municipal and industrial waste, and already large volumes of e-waste – could continue to increase worldwide [UNEP/GWMO, 2015[419]; Kaza et al., 2018]. The latest UNEP report included an even clearer statement than previous ones, namely that "Despite awareness of the global waste crisis, progress towards waste prevention and improved waste management is not occurring rapidly enough" [UNEP/GWMO, 2024: p. 42].

- The relevant international conventions and programs in this area have also been achieved only with significant compromises, and their implementation is progressing with difficulty.[420] This

[415] "The presently dominant industrial sociometabolic regime dates back no more than 300 years and is based on the use of fossil fuels. Its sustainability seems limited not only by the limitations of its energy resource base, but also by the transformations it triggers globally in various life sustaining natural systems. […] So this sociometabolic regime is bound to change as it erodes its natural base." (p. 6)

[416] "During industrialization, humanity has become a geophysical force on a planetary scale. Our data show, how the size of societies' metabolism has multiplied since 1900, resulting in a massive draw on material resources from the biosphere and the lithosphere and corresponding outflows of wastes and emissions. We find that biophysical growth has been speeding up significantly since the turn of the 21st century". (p. 139)

[417] "We do not wish to impoverish the environment any further and yet we cannot for a moment forget the grim poverty of large numbers of people. Are not poverty and need the greatest polluters? […] The environment cannot be improved in conditions of poverty."

[418] "China said they hope Rio+20 will develop green economy in a way that provides preferential treatment for developing countries in terms of market access, technology transfer and intellectual property rights, while not being used to create new barriers to trade."

[419] "The 21st century will witness an enormous increase in both quantity and composition of waste."

[420] Basel Convention, Stockholm Convention, Rotterdam Convention, Minamata Convention, SAICM and its follow-up, i.e. the GFC (2023).

statement is particularly applicable to the *Basel Convention* [UNEP/GEO, 2020][421] and the former strategy on sustainable chemicals management [SAICM, 2006; UN/GSDR, 2019[422]]. For this reason, it is particularly important that the new strategic framework on chemicals has set much more concrete and universally applicable time-bound targets using the deadlines of 2030 and 2035 (however, this is also not a legally binding instrument, so it is up to governments and stakeholders to decide how and to what extent they proceed with the implementation of these targets) [UNEP/GFC, 2024].

- With the extremely rapid escalation of plastic production, particularly the use of plastic packaging materials, the magnitude of plastic waste has increased significantly [Tsakona et al., 2021].[423] The quantity of the latter more than doubled between 2000 and 2019, and 22 Mt of this plastic pollution was released into the environment (Figure 3) [OECD, 2022a: p. 14]. It is estimated that, if current production and consumption trends continue at the same pace, the 460 Mt amount of plastic produced in 2019 and the 350 Mt of plastic waste could triple by 2060, and the 22 Mt of such pollutants released into the natural environment could double [OECD, 2022b: p. 6]. Consideration of this issue took a significant turn when the Parties to the *Basel Convention* included these substances in the list of hazardous wastes in 2019 (with some exceptions). Nevertheless, it will not be easy to substantially reduce their further production, international trade and environmental contamination [Diggle & Walker, 2022; Comolli, 2021[424]]. It was a major development in this regard that negotiations for preparing an international agreement aimed at reducing plastic pollution were launched at the end of 2022 [UNEP, 2022].[425]

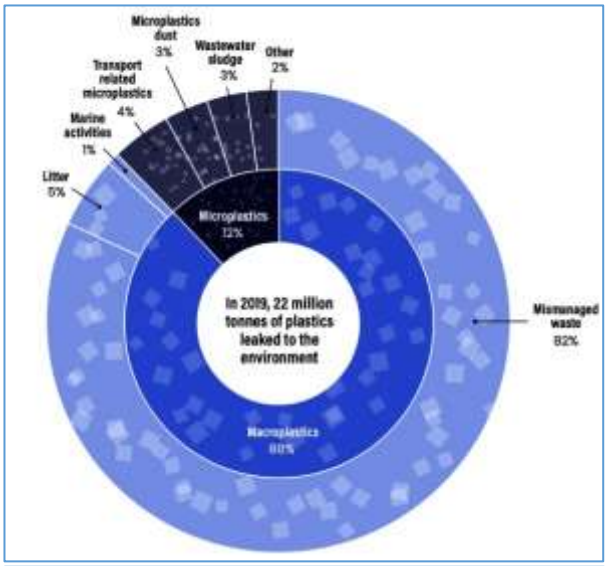

Figure 3 The source of the largest proportion of global plastic pollution entering the environment (22 million tons in 2019) was improperly managed waste (82%). [OECD, 2022a]

- There is a growing amount of pollutants in international 'public spaces' (i.e., in areas outside national jurisdiction), including the high seas, the Antarctic, outer space, and, of course, the atmosphere. While curbing this process is the objective of several conventions, there are currently

[421] "With increasing global demand for resources, the waste market has become a viable economic sector, estimated at US$ 410 billion a year, from collection to recycling. In a context of increasing costs for the safe disposal of hazardous waste, weak environmental regulations and enforcement, and increasing resource scarcity, this market creates opportunities for waste trafficking and illegal activities." (p. 90)

[422] "Both plastics and e-waste can, even when produced and consumed in developed countries, can end up in the landfills or recycling processes in developing countries." (p. 53); "it is becoming obvious that the 2020 goal will not be achieved. A future policy framework on sound management of chemicals and waste beyond 2020, bringing together all relevant sectors, raising ambitions and strengthening policies are needed." (p. 134)

[423] "While plastic packaging accounts for a large share of plastic waste, sectors such as fisheries, construction, agriculture, transport and electronics are also significant. Only around 10% of the plastic waste generated to date has been recycled". (p. 62)

[424] "The illicit trade in plastic waste is here to stay. Despite efforts of environmental campaigners and the warnings of scientists, we globally produce an extraordinary amount of rubbish. […] Besides carrying out an assessment of the illegal activities around the illicit trade in plastic waste, this report underlines great power imbalances between countries that produce the most waste and those that receive it." (p. 37)

[425] *The United Nations Environment Assembly* "1. Requests the Executive Director to convene an intergovernmental negotiating committee, commencing its work during the second half of 2022, with the ambition of completing its work by the end of 2024; […] 3. *Decides* that the intergovernmental negotiating committee is to develop an international legally binding instrument on plastic pollution, including in the marine environment henceforth referred to as the instrument, which could include both binding and voluntary approaches, based on a comprehensive approach that addresses the full lifecycle of plastic".

no international legal instruments associated with specific goals/targets for the elimination or substantial reduction of the vast quantities of such harmful substances accumulated in the sea, on the seabed, been 'abandoned' on the sixth continent, and exist as 'space debris' circulating around the Earth. Only guidelines and recommendations are available for voluntary actions by governments and relevant stakeholders in this regard.

- In the case of the marine environment, plastic pollution is the most widespread current problem, and its extent could triple within two decades [UNEP, 2021b].[426] Space debris in low-Earth and geostationary orbits poses a serious collision risk. Currently, these hazards are intensifying the fastest [NOAA, 2020; ESA, 2021[427]], so, regulation that impose legal obligations on these matters would be needed as soon as possible. This situation could even become a "tragedy of the commons" (to borrow Garret Hardin's apt phrase) in the sense that all nations can use the high seas and outer space, but without a legally binding obligation to take responsibility for the problems they cause in this respect [Leous & Parry, 2005; Muñoz-Patchen, 2018[428]].

Transitioning towards sustainability in consumption and production, as well as through circular economic development, can contribute to curbing those driving forces (root causes) that have so far led to significant pressures on the environment, including the release of large magnitude of pollutants and hazardous waste and the harms caused by them on a global scale.

- The implementation of the framework for sustainable consumption and production programs (10YFP) approved in 2012, was assessed at the 2021 session of the UN High-level Political Forum on Sustainable Development (HLPF). It was agreed that current development models that encourage unsustainable activities are exacerbating planetary environmental crises such as climate change, biodiversity loss, and pollution. To mitigate these challenges, more must be done [UN/10YFP, 2021].[429] Even greater expectations have been raised regarding the environmental efficiency of the 'circular economy' model, including tackling the problem of waste generation, with the observation that the application of the 'circularity' concept can play a major role in achieving other sustainable development goals as well [Valverde & Avilés-Palacios, 2021[430]; Andrade et al., 2021[431]].
- Since these approaches have not yet achieved breakthrough global results, new international programs of strategic importance adopted in 2023 have reinforced the importance of previous objectives and defined some new targets and means of implementation. Under the new *Global Strategy for Sustainable Consumption and Production* (2023-2030) "the objective is to support a decoupling of economic growth from environmental degradation and primary resource consumption that is compatible with the ecological thresholds of our planet, and to enhance human well-being leaving no-one behind." [UN, 2023: par. 1] The aim of the *Global Framework*

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[426] "The amount of marine litter and plastic pollution has been growing rapidly. Emissions of plastic waste into aquatic ecosystems are projected to nearly triple by 2040 without meaningful action." (p. 14)

[427] "The results from the evaluation of the scenario indicated that even when spaceflight is completely halted today, the amount of space debris objects in Low Earth Orbit is likely to increase." (p. 103)

[428] "Marine debris is a classic 'tragedy of the commons' environmental problem." (p. 257); "The tragedy of the space commons". (p. 19)

[429] VII. The Way Forward: "86. The Covid-19 pandemic has revealed the weaknesses of current development models […]. The same development models continue to feed three planetary crisis – climate change, biodiversity loss and pollution – of which the environmental, economic and social costs are unprecedented. The unsustainable consumption and production patterns that underpin these development models are now widely recognized as the root causes of these crises […] 87. The 10-Year Framework is a constituent element of the 2030 Agenda and key to maintaining its integrity […]. Efforts to implement Goal 12 should intensify by 2022 and beyond".

[430] "Alongside other positive impacts such as preventing deforestation, optimising the water cycle and eliminating waste, among others, there is a positive, direct link between achievement of the Sustainable Development Goals and implementation of circular economy." (p. 11)

[431] "[W]aste in an CE should be called resource that can be used by other production or consumption processes […]. CE has mainly been implemented from an industrial economy perspective, targeting better use of resources at the time of production and better waste management. […] Rather, the CE should aim for sustainability." (p. 21)

on Chemicals is "to prevent or, where prevention is not feasible, minimize harm from chemicals and waste to protect the environment and human health […]. It supports innovation to provide better products that are safer and sustainable by design and advance sustainable consumption and production patterns, including through resource efficiency and circular economy approaches." [UNEP/GFC, 2023: par. 5]

- In the global sustainable development program adopted in 2015, the interconnections between social, economic and environmental processes were pointed out much more clearly, and specific goals and targets were set or reinforced in several areas, while also indicating that all of these can be achieved together, i.e., in an integrated manner (through a synergistic approach due to their interdependences) [UN, 2015].[432] There have been grave deficiencies in the implementation of the program so far, but the more recent crises and conflicts that have emerged around the world have further exacerbated this. The UN reports highlighted the serious environmental implications of the failure to transition to sustainability so far [UN/DESA, 2021[433]; UNEP/GWMO, 2024[434]]. According to *The Pact for the Future*, adopted by participants of the recent high-level UN conference, "We are deeply concerned about rapid environmental degradation, and we recognize the urgent need for a fundamental shift in our approach in order to achieve a world in which humanity lives in harmony with nature. We must conserve, restore, and sustainably use our planet's ecosystems and natural resources to support the health and wellbeing of present and future generations. We will address the adverse impacts of climate change, sea level rise, biodiversity loss, pollution, water scarcity, floods, desertification, land degradation, drought, deforestation and sand and dust storms." [UN/Pact, 2024, p. 10]

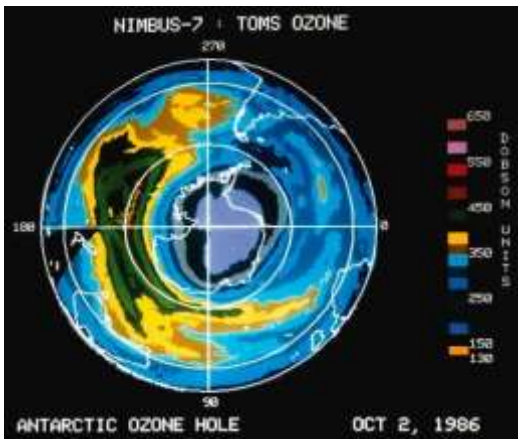
[432] "The interlinkages and integrated nature of the Sustainable Development Goals are of crucial importance in ensuring that the purpose of the new Agenda is realised." (p. 2) "13. The challenges and commitments […] are interrelated and call for integrated solutions."

[433] "A growing global population combined with the unsustainable use of natural resources is having a devastating impact on our planet – propelling climate change, destroying nature and raising pollution levels." (p. 50)

[434] "The first Global Waste Management Outlook (GWMO), published in 2015, provided a pioneering scientific global assessment of the state of waste management. It was also a call to action to the international community to recognize waste and resource management as a significant contributor to sustainable development and climate change mitigation. Since then, despite some concerted efforts, little has changed. If anything, humanity has moved backwards - generating more waste, more pollution and more greenhouse gas (GHG) emissions." (p. 9)

3. THE THREATENED OZONE LAYER

DANGEROUS ANTHROPOGENIC ENVIRONMENTAL IMPACTS
REACHING THE STRATOSPHERE



The confirmation of discovery of the 'ozone hole' from the outer space

"[T]he evidence is also rather strong that modest reduction of stratospheric ozone would be reflected in increased average incidence-rates for skin cancer."

James McDonald, 1971[435]

"[T]he damage to the ozone layer […] may endanger the continuance of human life on the planet."

Maurice Strong, 1973[436]

"The weighted mean projects an ozone recovery to 1980 levels, by 2056 with a 95 % confidence interval (2052–2060)."

Amos, M. et al., 2020[437]

The ultraviolet component of solar radiation is harmful to living organisms, but the ozone layer in the upper atmosphere filters out most of this radiation. In the first half of the last century, chemicals began to be invented that became useful in industrial applications and everyday life, which led to their production expanding and use growing rapidly worldwide. A few decades later, it was discovered that these substances, when they reach the stratosphere, destroy ozone molecules, thereby reducing their concentration. Scientists have done a lot to reveal this process, its causes, and dangerous consequences, but it has proven difficult to make decisions on appropriate international measures. Ultimately, the gradually strengthening cooperation aimed at preventing further endangerment of the ozone 'shield' developed through an understanding of the common responsibility and interdependence of societies in this regard, and this can be seen as exemplary with regard to solving other global problems unintentionally caused by human activities. The history of the discovery of this hazard and the development of scientific and political cooperation are reviewed and evaluated in this chapter.

[435] James McDonald's assessment of the potential consequences of the depletion of the ozone layer that was submitted to the United States House Subcommittee on Transportation Appropriations [McDonald, 1971: p. 7255].

[436] Statement by Maurice Strong, Executive Director of the UNEP [Strong, 1973; Andersen & Sarma, 2002: p. 373].

[437] This research team applied a model-weighting methodology to better understand Antarctic ozone depletion and damage and subsequent recovery and predicted the expected time for its 'healing', assuming that relevant international commitments are fully met [Amos et al., 2020: p. 9961]. According to other estimates, this process could take up to a decade longer, especially because, despite international obligations, 'illegal' atmospheric emissions of ozone-depleting substances (esp. freon emissions) have occurred since 2010 [Dhomse, 2019].

3.1. DISCOVERING THE SIGNIFICANCE OF AND THREATS TO THE OZONE LAYER

3.1.1. Ozone in the laboratory and in the atmosphere: experiments and hypotheses

3.1.2. Systematic measurements of atmospheric ozone amounts

3.1.3. Ozone concentration changes in the upper atmosphere: exploring the anthropogenic causes

3.2. IS THE OZONE LAYER IN DANGER AND SHOULD IT BE SAVED?

3.2.1. From the possible to the certain: achievements of international scientific cooperation

3.2.2. Enough reason to be cautious?

3.2.3. The great decisive turning point: the discovery of the 'ozone hole'

3.3. THE THREAT TO THE OZONE LAYER MUST BE ENDED: INTERNATIONAL LEGAL INSTRUMENTS

3.3.1. Substances threatening and non-threatening to the ozone layer

3.3.2. Phasing out ozone-depleting substances: science, technology, and politics

3.3.3. Solving the 'ozone problem' while exacerbating another global environmental hazard?

3.4. THE EFFECTIVENESS OF SCIENCE AND POLICY COOPERATION: WILL THE OZONE LAYER BE SAVED?

3.4.1. Phasing out the ozone layer depleting substances: the initial difficulties

3.4.2. The need for systematic efforts to "heal" the ozone layer

3.5. CONCLUSIONS AND LESSONS LEARNED

3.1. DISCOVERING THE SIGNIFICANCE OF AND THREATS TO THE OZONE LAYER

3.1.1. Ozone in the laboratory and in the atmosphere: experiments and hypotheses

The long history of studies on ozone, the ozone layer, and its vital role for the natural environment and human health – including the century-long period from the discovery of ozone molecules to the understanding of the role of this atmospheric trace gas in the stratosphere in filtering ultraviolet radiation from the Sun – is in itself a particularly interesting and instructive case in the development of natural science.

The 'smell of electricity' and the 'ozein'. Ozone was first identified as a peculiar odor in the air that was produced during experiments with electricity.

- A pale blue gas, described as having the 'smell of electricity' (or rather 'odor' due to its unpleasantness), was detected by Martinus van Marum in the 1780s when he was experimenting with an electrostatic generator [Andrews, 1874].[438] Christian F. Schönbein observed the same gas several decades later when he was working on the electrolysis of water and named it ozone, after the Greek word 'ozein' (to smell) [Schönbein, 1839].[439]
- There were several ideas about what kind of compound this gas was and how many atoms it could have in its molecular structure until, finally, Thomas Andrews carefully deduced that ozone was a variant (allotrope) of oxygen [Andrews, 1856].[440]
- Eight decades after Marum's discovery, Jean-Louis Soret made it clear that ozone is actually a triatomic oxygen molecule [Soret, 1867].[441] It was also clarified that ozone exists not only under laboratory conditions but also in the atmosphere, and then the systematic measurement of its atmospheric quantity began [Houzeau, 1872].

The upper atmosphere ozone layer and ultraviolet radiation. It again took decades to discover that atmospheric ozone mainly exists in the stratosphere and acts as a kind of shield, preventing a large part of the ultraviolet radiation from the Sun, which is dangerous to living organisms, from reaching the Earth's surface.

- From the 1880s onward, researchers turned their attention to the radiation absorption and transmission properties of ozone, which was made possible by the advent of spectroscopes. A milestone in the discovery and study of ozone in the upper atmosphere was when Walter Noel Hartley, based on the findings of other researchers, published his own results [Hartley, 1881]. His main conclusions were that ozone is a normal component of the upper atmosphere, where it is present in greater proportions than near the surface, and that it limits the ultraviolet spectrum of

[438] "Towards the end of the last century, Van Marum, while experimenting with his powerful electrical machine, observed that oxygen gas through which electrical sparks had been passed acquired a peculiar odour". (p. 347)

[439] "[B]ei der Electrolyse des Wassers an der positiven Electrode ein Geruch entwickelt wird, auffallend ähnlich demjenigen, den man beim Ausströmen gewohnlicher Electricität aus Spitzen wahrnimmt."

[440] "[O]zone, from whatever source derived, is one and the same body, having identical properties and the same constitution, and is not a compound body, but oxygen in an altered or allotropic condition." (p. 13)

[441] "Ces faits conduisent à supposer que l'ozone et l'oxygène diffèrent par le nombre d'atomes qui sont groupés pour former les molécules. L'une des hypothèses les plus simples, à cet égard, est celle que j'ai indiquée précédemment et dans laquelle on considère la molécule d'oxygène ordinaire comme formée de deux atomes, OO, et la molécule d'ozone comme formée de trois atomes OOO." (p. 5)

solar radiation, allowing only a little ultrashort-wave radiation from the Sun to reach the surface of the Earth, and the atmosphere has a blue tint because of this.[442]

- Confirming these conclusions, Charles Fabry and Henri Buisson revealed that the ozone layer, which absorbs a significant proportion of ultraviolet radiation, is indeed located in the upper atmospheric region [Fabry & Buisson, 1913].[443] Then, they measured that under standard atmospheric conditions,[444] the total ozone content – the total amount of ozone in a vertical column of air – would be equivalent to a layer at the Earth's surface only 3 millimeters thick. Fabry is most often cited in the scientific literature as the scientist who discovered the ozone layer.

The 'life cycle' of ozone in the upper atmosphere. Studies conducted in the first decades of the last century also revealed how and due to what natural processes the ozone layer can be continuously renewed, thereby constantly limiting the further passage of ultraviolet wavelength solar radiation.

- The identification of the possibility that ozone is formed by a photochemical process is attributed to Philipp Lenard. He demonstrated under laboratory conditions that ozone was formed from oxygen under the influence of ultraviolet light [Lenard, 1900].[445] Thirty years later, Sydney Chapman published how – with several simplifying assumptions – the two-way conversion of oxygen to ozone and ozone to oxygen could take place within the ten-kilometer strata of the atmosphere at an altitude of around 40 km and that these two processes of ozone formation and decomposition balance each other out (excluding intra-annual and daily variability) [Chapman, 1930].[446]

- Despite its simplicity and easy interpretation, the Chapman mechanism resulted in an overestimation of the amount of stratospheric ozone compared to the measured data. This led to the idea that ozone molecules could also be decomposed in another way, namely with the involvement of water vapor in the atmosphere [Bates & Nicolet, 1950].[447] A correct estimate of the amount of ozone in the upper atmosphere was not achieved, but this idea contributed to the search for other substances (catalysts) that may influence this process.

- Paul J. Crutzen proposed in 1969 and then derived the effect of nitrogen compounds entering the stratosphere in the photochemical process of ozone destruction [Crutzen, 1969[448]; Crutzen,

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[442] "The foregoing experiments and considerations have led me to the following conclusions: 1st. That ozone is a normal constituent of the higher atmosphere. 2nd. That it is in larger proportion there than near the earth's surface. 3rd. That the quantity of atmospheric ozone is quite sufficient to account for the limitation of the solar spectrum in the ultra-violet region, without taking into account the possible absorption caused by the great thickness of oxygen and nitrogen. 4th. That the blue tint of the atmosphere is due to ozone." (pp. 127-128)

[443] "La limitation du spectre solaire, un peu au-dessous de la longueur d'onde 3000, certainement due à l'absorption atmosphérique, a été attribuée à la présence de l'ozone dans l'atmosphère. Cette hypothèse, d'abord émise par Hartley, n'est appuyée que sur l'existence d'une forte bande d'absorption de l'ozone dans l'ultra-violet." (p. 196) "L'hypothèse la plus probable est que l'ozone existe seulement dans la très haute atmosphère, où il serait produit par la partie extrême du rayonnement ultra-violet solaire, qui, étant fortement absorbé par l'oxygène, ne peut agir que sur les couches les plus élevées de l'atmosphère." (p. 206)

[444] 0°C temperature, 1 atm pressure.

[445] "Die Kathodenstrahlen waren ein erstes Beispiel einer Strahlung, welche die sie verschluckende Luft in einen eigentümlichen Zustand versetzt, dem ähnlich, welchen elektrostatische Kräfte in ihr hervorbringen können. Die Luft wird elektrisch leitend, ihr Sauerstoff wird teilweise zu Ozon und es bilden sich Kerne der Dampfcondensation in ihr." (p. 486)

[446] "The ozone is supposed formed and decomposed in the 10 km layer; formation is attributed ultimately to dissociation of O_2 by ultra-violet radiation (1300-1800 Å); the ozone is supposed decomposed by longer-wave radiation (2300-2900 Å) […] In so far as dissociation ($O_3 = O + O_2$) and re-formation ($O + O_2 = O_3$) balance one another, they have no ultimate effect on the amount of ozone". (p. 125)

[447] Hydrogen radicals (H, OH, HO_2) produced from water molecules by photolysis catalyze the decomposition of ozone molecules.

[448] "In view of the results of this study it is conceivable that at least part of the solution of the problem of the ozone distribution might be given by the introduction of photochemical processes other than those treated here. The influence of nitrogen compounds on the photochemistry of the ozone layer should be investigated. In the first place observations on the concentrations of such gases in the stratosphere and needed." (p. 385)

1970[449]]. Ernő Mészáros also referred to this mechanism: "The fundamental change in the theory occurred when Crutzen (1970, 1971) proposed that ozone decomposition is triggered by nitrogen monoxide […]. Under natural conditions, stratospheric NO originates from soil […] derived from nitrous oxide." [Mészáros, 1997: p. 40]

3.1.2. Systematic measurements of atmospheric ozone amounts

The respective measurements began more than a hundred years ago at a few European sites,[450] and then continued within the framework of an international network. The total amount of ozone in a vertical column of atmosphere was measured with a spectrometer. Later, upper atmospheric measurements became possible using balloons and then satellites. These made it possible to more accurately detect the concentration of ozone as a function of height, the location of its major presence (about 90 percent) in the stratosphere, and the distribution of atmospheric ozone along geographical latitudes. Based on this latter knowledge and upper atmosphere circulation data, it became even clearer why total ozone content is significantly higher in the polar regions, while ozone is mainly formed over the tropics under the influence of solar radiation.

The initiation of regular atmospheric ozone measurements was due to Gordon Dobson, who first developed a spectrograph and then a relatively simple spectrometer (spectrophotometer) for this purpose. An improved version of this instrument has been used in many parts of the world for many decades. In recognition of his work, the total column ozone in the atmosphere is given in Dobson units (DU): the above-mentioned 'fictitious' amount of ozone with an average thickness of 3 millimeters on the Earth's surface would correspond to 300 DU.

- By analyzing data from observations first made at Oxford in 1924-1925, Dobson came to important conclusions about the ozone layer, especially regarding its approximate height of 40-50 km from the earth's surface [Dobson, 1926].[451] After many years, he revised this estimate to a much more correct value based on more accurate measurements at a location in Switzerland: "The chief result of these measurements at Arosa was to show with certainty that the average height of the ozone in the atmosphere was about 22 km and not about 40-50 km as had been thought before. They also gave a fair idea of the vertical distribution, showing that the main changes took place at heights between 10 km and 25 km. This made it much easier to understand why changes in the total amount of ozone should be so closely correlated with conditions in the upper troposphere and lower stratosphere" [Dobson, 1968: pp. 396-397].
- The establishment of an international observational network was organized by Dobson himself in 1928, and its expansion to several regions was then promoted by the International Ozone Commission (IO_3C),[452] founded in 1948, of which Dobson became the first president. Initially, the International Union of Geodesy and Geophysics (IUGG) established an Ozone Subcommittee

[449] "Bates/Hays (1967) have indicated that N_2O, possibly produced by microbiological action in the soil and diffusing upwards through the troposphere, may partly be converted to 'odd nitrogen' (NO and NO_2) by a photodissociation process in the stratosphere. As will be shown in this paper, on this hypothesis the NO and NO_2 concentrations have a direct controlling effect on the ozone distributions in a large part of the stratosphere, and consequently on the atmospheric ozone production rates." (p. 302)

[450] Schönbein's Central European ozone measuring network operated for a few decades after 1850; at that time, such measurements were also carried out for a few years in Hungary (Szeged and Sopron).

[451] "It has been shown that oxygen is transformed into ozone by wave-lengths in the oxygen absorption band (<1800 Å), and that ozone is decomposed again by (at least some of) the wave-lengths which it absorbs. If the ozone be formed by the action of ultra-violet light, there will probably be a region at about 40 to 50 km, where the concentration of ozone will be governed by the equilibrium between the rate of formation by the shorter wave-lengths and the rate of decomposition by the longer wave-lengths." (p. 692)

[452] Established within the framework of IUGG/IAMAP.

in 1930, and the above-mentioned commission became its successor [Munn, 1977].[453] This topic also fit well into the program of the International Geophysical Year (IGY) organized in 1957/1958, and that is when the Global Ozone Observing System (GO_3OS) began operating.

- The network was expanded, and surface-level measurements of total ozone were supplemented by measurements made by means of balloons and then satellites. When it became apparent that more accuracy than was possible with the Dobson instrument (the 'Dobson-meter') was needed, the automated measuring instrument (the 'Brewer-spectrophotometer') developed by Alan West Brewer in the 1970s began to be widely used.
- Based on the measurement data, the variability of the total ozone content, its dependence on geographical latitude, and especially the large interannual variation of the state of the ozone layer over the Antarctic region could be determined and attributed to natural causes [Dobson, 1968].[454] Among the factors causing variability on a longer time scale, the effect of the 11-year 'sunspot cycle' was also examined: the increased ultraviolet radiation from the Sun caused the formation of more ozone in the stratosphere, which resulted in a temporary increase in ozone concentration of a few percent [Dütsch, 1974[455]; Keating, 1981[456]].

No trend-like change was detectable in the time series of total ozone content based on data series associated with various measurements until the end of the 1970s.

- It was suggested as early as 1971 that certain human activities could cause the 'thinning' of the ozone layer, but the measurement data at that time did not confirm this. In fact, in both hemispheres, a temporary minimal increase in the amount of total ozone was experienced until 1970 and then until the end of the 1970s, which was explained by natural causes [London & Kelley, 1974; John et al., 1981[457]; Reinsel et al., 1981].
- Satellite observations over Antarctica have confirmed the same; consequently, the decrease in ozone – the development of the 'ozone hole' above the southern polar region – only started in the late 1970s, as revealed sometime later [Staehelin et al., 2001].[458]

Cooperation on atmospheric ozone monitoring intensified after the 1957/1958 International Geophysical Year as interest grew in the ozone layer's role in radiation transmission in the atmosphere, as well as its interactions with geophysical and meteorological processes.

- The ozone program of the International Geophysical Year was therefore planned and organized by the ozone commission (IO_3C) operating under the auspices of the IUGG; after a while, the World Meteorological Organization also joined this activity. The measuring stations of this

[453] "The international conference on stratospheric ozone was held in Paris in 1929. This led to the formal involvement of international scientific organizations in 1930, when a Sub-Commission on Ozone was established within the International Union of Geodesy and Geophysics of the International Council of Scientific Unions. After the war, a separate International Commission on Atmospheric Ozone was organized." (p. 78)

[454] "One of the more interesting results on atmospheric ozone which came out of the IGY was the discovery of the peculiar annual variation of ozone at Halley Bay […]. It was clear that the winter vortex over the South Pole was maintained late into the spring and that this kept the ozone values low. When it suddenly broke up in November both the ozone values and the stratosphere temperatures suddenly rose." (p. 403)

[455] "Variations in the Upper Stratosphere. The 15 year series of Umkehr observations at Arosa shows for the ozone concentration in the upper stratosphere a variation which seems to be correlated with the sunspot number, whereby a certain time lag is indicated." (p. 1503)

[456] "Observational evidence and theoretical predictions of the response of ozone to solar variations are reviewed […] and 11-year solar cycle variations are discussed. Photochemical models indicate that the observed 3% variations in global mean ozone over the solar cycle can be accounted for by solar UV variations which are not inconsistent with recent solar measurements." (p. 321)

[457] "Ground-based total ozone measurements through 1979 show an average ozone increase of 1.5 ± 1.0%". (p. 7310)

[458] "[T]he total ozone mean values and ozone distributions over Antarctica were similar at the beginning and the end of the 1970s (measured by the TOMS instrument on board Nimbus 7), providing further evidence that the ozone hole started to develop toward the end of the 1970s." (p. 259)

Global Ozone Observing System (GO_3OS) rapidly multiplied worldwide. The data was collected in the World Ozone Data Centre (WODC) from 1960 onwards and then at the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) from 1992, thus facilitating their uniform processing. This network became part of the Global Atmosphere Watch (GAW) in 1989 under the name the Global Atmospheric Ozone Monitoring Network [WMO, 2014]. As mentioned, since the late 1970s, surface measurements have been supplemented by satellite observations of the ozone layer.[459]

- In order to improve the accuracy, the regular verification and calibration of the measuring instruments began, and international meetings were held on data quality issues, especially in relation to the earlier measurements. One such meeting was held in Hungary (Siófok) in 1967.

3.1.3. Ozone concentrations changes in the upper atmosphere: exploring the anthropogenic causes

The clash of arguments involving the pros and cons lasted for a decade and a half from 1970 onwards at varying intensity, in which on one side were those researchers who revealed the anthropogenic threat to the ozone layer and on the other were those who disputed the validity of this claim. The debate first revolved around the possible ozone-depleting effects of nitrogen oxides emitted by airplanes and space rockets flying in and through the stratosphere. Subsequently, the decisive turning point in the identification of human activities indirectly affecting the ozone layer was when it was discovered that freons – produced by the chemical industry and widely used – could reach the upper atmosphere and that the chlorine atoms released from them under the influence of ultraviolet radiation from the Sun destroy ozone molecules, decreasing their concentration.

Supersonic aircraft and nitrogen oxides. In contrast to the previous ideas, Paul J. Crutzen came up with a completely new hypothesis in 1969 (mentioned above), which led to the consideration of the possibility of ozone layer damage due to then-planned supersonic aircraft.

- Crutzen estimated the effect of nitrogen oxides on stratospheric ozone by means of theoretical methods in a paper published in April 1970; he later refined this assessment based on more recent data [Crutzen, 1970[460]; Crutzen, 1971, 1979[461]]. In preparation for the 1972 UN Conference on Environment and Development, a scientific conference held in July 1970 (Williams College, US-MA) also addressed the potential environmental effects of passenger transport using supersonic aircraft ascending to the stratosphere (SST).[462] Preliminary plans at that time were for about five hundred such aircraft to be flying in the sky within a decade and a half. The conclusions adopted at the conference stated that nitrogen oxides and other pollutants emitted by the engines of these aircraft would *not* endanger the ozone layer [SCEP, 1970].[463]

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[459] NASA (1979-); ESA (1995-)

[460] "It can be seen that the destruction of odd oxygen by the nitrogen oxides is of the same order of magnitude as the production by photodissociation of molecular oxygen. Reductions of odd oxygen by odd nitrogen is, according to these estimates, dominant between approximately 25 and 40 km. […] There is a distinct possibility that nitrogen oxides are of great importance in ozone photochemistry." (pp. 323, 325)

[461] "Now it is clear that the oxides of nitrogen play an important role in defining the abundance and distribution of stratospheric ozone. Interest in the stratospheric role of the oxides of nitrogen started with the recognition that NO and NO_2 could catalyze the destruction of ozone in the stratosphere" (p. 485)

[462] Supersonic Stratospheric Transport (From the 1960s onwards, the Boeing company began designing such aircraft.)

[463] "(1.) The added SST water vapor in the stratosphere […] The reduction of ozone due to water vapor interaction (in a static photochemical model) has been estimated to lie well within the present day-to-day and geographical variability of total ozone. (2.) The direct role of quantities of CO, CO_2, NO, NO_2, SO_2 and hydrocarbons in altering the heat budget is small. It is also unlikely that their involvement in ozone photochemistry is as significant as water vapor."

- According to his own recollections, Crutzen was upset that the role of nitrogen oxides in ozone depletion was considered negligible, in contrast to results based on his derivation published a few months earlier,[464] so in his next article, he dealt with the risks posed by SST aircraft [Crutzen, 1971]. Harold Johnston criticized the findings of the aforementioned SCEP report more harshly and provided numerical estimates of how much damage to the ozone shield could be caused by nitrogen oxide emissions from the planned SST aircraft fleet [Johnston, 1971].[465]
- The US Congress discussed this issue in several public hearings until March 1971, but the concerns there raised were dismissed by William M. Magruder, head of the office responsible for the SST program, who stated that there was no evidence of any significant adverse effects [Primack & Hippel, 1974].[466] Yet both Houses of Congress voted down further support for this costly program in 1971. The decision was influenced by a growing public environmental awareness, which also played a role in the enactment of the first environmental protection law in the USA in 1970 and the launch of the Earth Day movement.
- The production of the supersonic Concorde aircraft continued under Anglo-French cooperation and, in parallel, the Russian Tupolev-144 aircraft. The first prototype of the latter entered service in 1968, a few months before Concorde's first passenger flight. The threat to the ozone layer was not raised (or only not published) in connection with the Tu-144, but some scientists may have been somewhat aware of the risk since the ozone layer had also been examined from the late 1970s onwards by means of this aircraft, which could reach a very high altitude [Osechkin & Smyshlyaev, 2018].[467]
- In addition to the problems of high costs and noise levels, the fate of Concorde was linked to the same environmental concerns and controversies from the early 1970s onward as those referred to above in connection with the SST plans in the USA. In this case, too, several experts drew attention to the possible threat to the ozone layer [Nicolet, 1972[468]; Allen, 1976[469]; Oliver et al., 1977[470]].
- After the US abandonment of the SST program, it became crucial for the proponents of the Anglo-French supersonic aircraft program to avoid any recommendations being made against it at the

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[464] "Although the paper in which I proposed the important catalytic role of NOx on ozone destruction had already been published in April, 1970, clearly the participants in the study conference had not taken any note of it. […] I was quite upset by that statement. Somewhere in the margin of this text I wrote 'Idiots'." [Crutzen, 1995: p. 196]

[465] "[I]f concentrations of NO and NO_2 are increased in the stratosphere by the amounts accepted by the SCEP report and by governmental agencies, then there would be a major reduction in the O_3 shield (by about a factors of 2 even when allowance is made for less NO_x emission than SCEP used)." (p. 522)

[466] "According to existing data and available evidence, there is no evidence of likelihood that SST operations would cause significant adverse effects on our atmosphere or our environment. This is the considered opinion of the scientific authorities who have counseled the government on these matters over the past five years." (p. 20)

[467] "В 1977 г. впервые в СССР измерения концентрации озона были осуществлены на сверхзвуковом транспортном пассажирском самолете Ту-144" (p.41). "Двумерная модель ЛГМИ – РГГМУ использовалась для […] получения численных оценок влияния на озоновый слой выбросов стратосферной авиации." (pp. 49-50)

[468] "[L]a présence du monoxide d'azote NO conduit à des réactions importantes dans la stratosphère. Il y a un équilibre photochimique immédiat entre the monoxide d'azote NO et le peroxyde de l'azote NO_2. Ces deux molécules constituent alors un cycle catalytique qui détruit l'ozone. D'où le danger souvent proclamé de la pollution de la stratosphère par les avions supersonique qui produisent par leur combustion des oxydes d'azote." (p. 1436)

[469] "The Secretary of Transportation recognized that in evaluating the environmental costs of admitting Concorde – air pollution, noise, stratospheric impact, and fuel consumption – objective standards existed only for measuring the impact of noise and air pollution. […] The effect of the exhaust emissions of supersonic transports on the earth's ozone layer has been one of the most widely debated aspects of supersonic flight." (pp. 441, 443)

[470] "The three major studies (CIAP, 1974; NAS, 1975; COMESA, 1975) […] agreed with regard to the existence of the aircraft NO_x effect on ozone, but disagreed – by about a factor of six – as to its magnitude for aircraft (such as the Concorde SST) at 17 km […]. The NAS and CIAP studies both concluded that subsonic as well as supersonic aircraft would reduce the ozone column." (p. S-2)

UN conference planned for 1972 [Hamer, 2002].[471] Further, with a few Concorde flights, they wanted to prove that the speculations about the harmful effects on the ozone layer were unfounded [U.K./HC, 1976].[472]

- The SST program in the USA was therefore terminated (not primarily for environmental reasons, but due to a few serious accidents and the high costs), and sometime later, the Concorde and Tupolev projects also stalled. Earlier visions called for hundreds of supersonic aircraft to be constructed, but instead, only a few more than ten of both the Concorde and the Tu-144 were made, which last took to the skies about twenty years ago.

Another hypothesis: space rockets and chlorine in the stratosphere. With the boom in space exploration, booster rockets crossed the stratosphere, the operation of which was accompanied by the release of chlorine compounds (HCl). The assessment of possible environmental problems was initiated by the US Space Agency (NASA) in the early 1970s. The possibility of ozone depletion due to chlorine was also raised in 1973 at a conference organized by the International Association of Geomagnetism and Aeronomy (IUGG/IAGA). (The proceedings of this Kyoto meeting were published in 1974 and included the texts of the two lectures referenced below.)

- It was revealed that chlorine could catalyze the breakdown of ozone molecules more effectively than nitrogen oxide, but there was debate about the sources from which chlorine compounds might enter the stratosphere. In addition to natural emission sources at the surface, volcanic eruptions were attributed a role in this [Stolarski & Cicerone, 1974[473]; Kowalok, 1993[474]].

- Similar to the nitrogen oxide emissions from supersonic aircraft (SST) flying in the stratosphere, it has been suggested that chlorine compounds emitted by space launch systems (STS) may also cause damage to the ozone layer [Wofsy & McElroy, 1974[475]; Stolarski & Cicerone, 1974[476]].

The synthesis of freons and the recognition of their outstanding properties led to a huge change, primarily in refrigeration technology, but the production and international trade of these chemicals also increased due to numerous other applications of these and some other halogenated hydrocarbons (e.g., halons).

- Compounds called freons, consisting of carbon, chlorine, and fluorine atoms, were first synthesized in 1928 by Thomas Midgley Jr.'s chemical expert group (at a company with the eloquent name Frigidaire). Actually, the term 'Freon' was introduced in 1931 as a trademark for the first synthesized refrigerant R-12 or Freon-12; however, later, a wide range of fluoroproducts were named freons. These substances proved to be so useful (among other things, as refrigerants and aerosol can propellants) that they were produced in increasing quantities from the 1930s

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[471] "The [Brussels] group's aims can be gleaned from a note laying out Britain's position prior to a secret meeting in Geneva in December 1971 […]. Written by an official in what was then the Department of the Environment, it says that Britain wanted to restrict the scope of the Stockholm conference and reduce the number of proposals for action. […] At the top of the list were controls on sonic booms from aircraft and pollution in the upper atmosphere. These measures would have seriously damaged the economics of the Anglo-French supersonic airliner, Concorde."

[472] The Secretary of State for Trade and President of the Board of Trade (Mr. Peter Shore): "I should like to make a statement on Concorde operations to the United States. As the House will be aware, the United States Secretary of Transportation, Mr. Coleman, announced yesterday his decision on the application by British Airways and Air France for up to two flights each per day to John F. Kennedy Airport, New York, and one each per day to Dulles International Airport, Washington. He allowed their application in full, for a trial period not to exceed 16 months. […] I believe services during this period will demonstrate that they will have a minimal effect on the environment."

[473] "ClO_x is more efficient for ozone destruction than NO_x […]. Large volcanic eruptions which penetrate to the middle or upper stratosphere where most of the ozone destruction occurs could leave a noticeable local ozone hole." (p. 1614)

[474] "Research attention turned to the role of chlorine in the stratosphere in 1972, when scientists at the U.S. National Aeronautics and Space Administration (NASA) recognized that the space shuttle's solid rocket boosters would inject chlorine directly into the stratosphere. Until that time, scientists thought that volcanic eruptions were the only source of stratospheric chlorine". (p. 17)

[475] "The work on chlorine had as its impetus the possible modification of the stratosphere by the space shuttle. The shuttle now under development and scheduled for operation in the 1980's, will emit HC1 as an exhaust product." (p. 1582)

[476] "[E]xplosive volcanic eruptions and solid fuel rockets may directly inject chlorine into the stratosphere". (p. 1610)

onwards, primarily in DuPont company plants, and were distributed and used all over the world. (It is a peculiar parallel that the development of an international network of atmospheric ozone measuring stations began in 1928, without even suspecting that the ozone-damaging effects of freons would be revealed a few decades later.)

- By the early 1970s, nearly one million tons of freons were being produced globally per year. The term 'freon' was already applied to all chlorofluorocarbons or CFCs (fully halogenated hydrocarbons) but also to the hydrochlorofluorocarbons or HCFCs (partially halogenated hydrocarbons consisting of at least one hydrogen atom). (Later, this term was extended to include 'ozone-friendly' compounds, i.e., chlorine-free hydrofluorocarbons or HFCs, such as the refrigerant HFC-134a or Freon-134a.) The category of halogenated hydrocarbons or halocarbons also includes halons containing bromine atom(s), produced in increasing quantities since the middle of the last century and used primarily in fire extinguishers.

The possible effect of freons on the ozone layer was raised, but for a while, this suggestion only attracted some interest in scientific circles because it was not yet supported by data from upper atmosphere measurements.

- Mario J. Molina and Sherwood F. Rowland deduced in 1974 that freons (Freon-11 and Freon-12)[477] released into the atmosphere can reach the stratosphere, and the free chlorine atoms produced as a result of their decomposition (their dissociation by photolysis) under the influence of ultraviolet radiation can break down ozone molecules [Molina & Rowland, 1974].[478] This does not occur immediately after the atmospheric emissions of freons near the surface, as it takes some time for them to reach high altitudes. It was also made clear that it may take a long time for the ozone layer to recover even if the amount of chlorine entering the stratosphere decreased in the future.[479]

- The analysis by Molina and Rowland was based on findings by James Lovelock, who, studying the measurements taken in Ireland in 1970, concluded that, e.g., Freon-11 (CCl_3F), which he considered harmless, was present everywhere in the northern hemispheric atmosphere [Lovelock, 1971].[480] After a while, his team carried out observations in the Atlantic Ocean and found this substance everywhere in the air and in the sea [Lovelock et al., 1973].[481] In his 1995 Nobel Prize memoirs, Rowland referred to the significance of these measurements and findings when he began his own research [Rowland, 1995].[482]

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[477] CFC-11 (Freon-11, F-11): $CFCl_3$ or CCl_3F; CFC-12 (Freon-12, F-12): CF_2Cl_2 or CCl_2F_2.

[478] "The most important sink for atmospheric $CFCl_3$ and CF_2Cl_2 seems to be stratospheric photolytic dissociation to $CFCl_2$+Cl and to CF_2Cl+Cl, respectively, at altitudes of 20-40 km. […] An extensive catalytic chain reaction leading to the net destruction of O_3". (p. 810)

[479] "One important corollary of these calculations is that the full impact of the photodissociation of CF_2Cl_2 and $CFCl_3$ is not immediately felt after their introduction at ground level because of the delay required for upward diffusion up to and above 25 km. If any Cl atom effect on atmospheric O_3 concentration were to be observed from this source, the effect could be expected to intensify for some time thereafter. A lengthy period (of the order of calculated atmospheric lifetimes) may thus be required for natural moderation, even if the amount of Cl introduced into the stratosphere is reduced in the future." (p. 812)

[480] "[A]bout 106 tons of fluorine compounds are released each year into the atmosphere, and these include halomethanes from aerosol dispensers, fire extinguishers, refrigerant fluids and anaesthetics, and sulphur hexafluoride from electrical equipment. [… But] carbon fluorides in the atmosphere are not in any sense a hazard […]. Air arriving at the monitoring site from a north-westerly direction does not pass over any source of either CCl_3F or SF_6 and so the concentrations measured under these conditions can be regarded as representative of the northern hemisphere background." (p. 379)

[481] "CCl_3F […] found in the air and in the sea wherever and whenever they were sought. […] CCl_3F is one of the few substances present and easily measured in the air which is wholly anthropogenic in origin". (pp. 194-195)

[482] "The starting point for that work was the discovery by Jim Lovelock that the molecule, CCl_3F, a substance for which no natural sources have been found, was present in the Earth's atmosphere in quantities roughly comparable to the total amount manufactured up to that date." (p. 273)

- Studies have established that freons are stable (inert) in the lower atmosphere, but when they reach the stratosphere, they break down under the influence of ultraviolet radiation, and the chlorine atoms thus released can break down ozone molecules via a chain reaction.[483]

The 'ozone-depleting freon' hypothesis had an extraordinary impact on further scientific research and the initiation of the first interventions.

- Scientific publications confirming the above conclusion and extending it to other chemicals appeared one after another [Nicolet, 1976[484]; USA/NAS, 1976[485]; Hudson et al., 1977]. Besides these, articles again questioning the harmful effects of these compounds were published [e.g., Scorer, 1974][486]; likewise, doubt was raised about such injurious implications in the statements made by representatives of chemical companies interested in the production and trade, including DuPont.
- In view of the new measurement data and concerns about the increasing risk of health hazards resulting from the 'thinning' of the ozone layer, in 1978 – as a first step and compromise solution – the use of freon as a propellant in some aerosols was banned in the USA,[487] and within a short time, similar bans were introduced in some other countries.[488] However, other applications continued to be permitted (e.g., freon as a refrigerant) because, on the one hand, it was not clear what environmentally friendly and economical alternatives could be used to replace these ozone-depleting substances, and on the other, the majority of industry representatives still did not consider the claim about the ozone layer-threatening effect of freons to be sufficiently convincing.

* * *

Following the discovery of the ozone layer and understanding its significance for human life and the biosphere, the identification of factors that could endanger this upper atmospheric component of the Earth's environment began. Within a short time, it became clear that the ozone damage in the stratosphere resulting from supersonic airliners and space rockets was negligible. It then emerged that synthetically produced freons, which had proven useful in various applications and were considered safe in all respects, could, in fact, pose a real threat to the ozone layer, but precise environmental observations were still lacking to validate (verify) this theoretically derived finding.

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[483] In the stratosphere, chlorine atoms released from freon react with ozone molecules to form chlorine monoxide, from which chlorine atoms are released again, acting as a catalyst to break down more and more ozone molecules. Bromine atoms contained in halons also participate in this ozone-depleting process.

[484] "Dans le cas du brome, on peut également écrire un cycle catalytique analogue à celui du chlore". (p. 157)

[485] "Resumption of exponential growth in the production and use of CFMs could well occur and lead to a doubling of their release rate within 10 yr. Even if the release rates became constant at that point, they would cause a doubling in the expected ozone reduction". (p. 20)

[486] "It may be thought that incumbent on the likes of me to say precisely what will happen to the chlorine from Freon, but it is first the duty of the chemists to find out what is up there all the time and consider all the hundreds of other reactions nature is capable of before predicting doom from one of them." (p. 140)

[487] March 1978: ban on the nonessential use of CFCs in aerosols under Toxic Substance Control Act and the Federal Food, Drug and Cosmetic Act.

[488] Canada, Denmark, Norway, Sweden.

3.2. IS THE OZONE LAYER IN DANGER AND SHOULD IT BE SAVED?

3.2.1. From the possible to the certain: achievements of international scientific cooperation

There were above references to the beginnings of cooperation related to the observation of atmospheric ozone and the study of the ozone layer, such as the activities under the auspices of the International Ozone Commission (IUGG/IO_3C, 1948-), the Global Ozone Observing System (GO_3OS, 1957-), the World Ozone Data Centre (WODC, 1960-), and the important outcomes of the 1973 conference of the International Association of Geomagnetism and Aeronomy (IUGG/IAGA). In the early 1970s, during the preparations for high-level forums – the 1972 UN conference (UNCHE, Stockholm) and the 1975 pan-European conference (CSCE, Helsinki) – the 'ozone problem' was raised, but the discussion reflected the participants' different perceptions of the scientific knowledge at the time, which was obviously also influenced by the different economic situations and interests of their countries in connection to this problem and its possible anthropogenic causes. Based on the ever-expanding body of scientific research on this matter, a consensus emerged in the late 1970s that there may be a need for action that could at least help clarify the risks and even mitigate them as a precaution. The fundamental turning point was brought about by the discovery of the 'ozone hole' over Antarctica in 1984, which accelerated negotiations on concrete measures to protect the ozone layer.

The issue of the release of some pollutants into the atmosphere that was suspected of affecting the ozone layer was discussed during several international meetings in the early 1970s, including those mentioned above, but it was not possible to reach a compromise on whether this peril should be indicated somehow in the outcome documents of these events.

- The provision of a science-based background for the 1972 UN conference was the aim of the compilation in which authors, in consultation with numerous experts from all around the world, reviewed the environmental processes considered to be the most critical at the time, their possible causes, and consequences. Among these, they alluded to the releases from supersonic aircraft engines that could threaten the ozone layer [Ward & Dubos, 1972].[489] This hazard was indeed discussed in the course of the informal consultations during the run-up to the conference. Primarily due to British and French interests in the development of the Concorde aircraft, the representatives of these two countries managed to ensure that not even an indirect reference to that potential effect was included in the action plan adopted in Stockholm [UN, 1972[490]; Engfeldt, 2009[491]].
- During the run-up to the 1975 pan-European conference (CSCE), it was even more difficult to avoid the 'ozone problem' when the text of the environmental chapter was negotiated since there was already more knowledge not only about supersonic nitrogen oxide exhausts but also about the presumably much more pronounced ozone-depleting effect of freons, as revealed in a study

[489] "It has also been suggested that nitrates and sulphates from volcanos – or supersonic exhaust – can unite with the critical supply of ozone and deplete the upper atmosphere of one of the essential elements in the planet's anti-radiation shield. It is […] that has led some scientists to advocate caution in any massive development of supersonic transport." (p. 269)

[490] "Some speakers were highly critical of the development of supersonic aircraft, which, they claimed, could have harmful global effects." (p. 47)

[491] U.K. and France: "[T]he Ambassadors of these two countries made two demarches to the Swedish foreign minister […] in order to secure that no substantive resolution would be adopted on the supersonic transport (SST) issue. […] the UK specifically wanted to leave out a number of subjects of the Stockholm action plan, including controls on sonic bombs and pollution in the upper atmosphere […]. As has been shown, the Conference did not adopt any recommendations on these areas." (pp. 77-78)

published in June 1974 [Molina & Rowland, 1974]. The US representative raised this issue at a forum in December 1974 (in Oslo),[492] but for reasons similar to those in 1972, this topic did not explicitly appear in the final document in 1975 (CSCE, Helsinki).[493] In contrast, this risk was taken more seriously in the scientific community. The first result of international scientific cooperation on this matter was the assessment prepared by a group of experts in 1975, in which they discussed the possible ozone-depleting effects of both supersonic aircraft exhaust gases and freons (CFCs). Above all, they considered further observations and research necessary: "present knowledge has shown clearly that there is a lack of understanding in a number of important aspects. Whilst this lack of understanding results in considerable divergence of opinion as regards the urgency of this problem, the prudent course of action at present seems to be to step up efforts immediately so as to reduce the scientific uncertainties as rapidly as possible." [WMO, 1975: p. 2]

- At the conference on global climate change held in Geneva in February 1979, several participants mentioned atmospheric emissions potentially affecting both the climate and the ozone layer [WMO, 1979b]. The opening speech was given by Robert M. White (USA): "It is hard to be complacent when we know that the population of the world will need increasingly to turn to nitrogen fertilizers to maintain agricultural production with the potential for releasing nitrogen compounds which can alter the photochemical balance of the stratospheric ozone. The potential effect on stratospheric ozone of the oxides of nitrogen released in supersonic flight, and of chlorofluoromethanes (CFMs) used as refrigerants or propellants also raise the issue of human impact upon climate." (In this regard, at that time, the focus was on two already widely used freon compounds or chlorofluoromethanes, namely, Freon-11 and Freon-12).[494] Robert E. Munn (Canada) and Lester Machta (USA) summarized the outcomes of theoretical models that showed that different above-mentioned emissions have opposing effects on the ozone layer.[495] John B. Mason (U.K.) referred to both the nitrogen oxide emissions from Concorde aircraft and freons but concluded that within a decade or two, these would have no or only minimal effects on the ozone layer.[496] (Perhaps to support the official British position at the time, Mason also noted that the U.K.'s share of global CFC production was only 6%.)
- So, the 'ozone question' with its uncertainties and its connection to climate change was raised at this 1979 meeting, but the finally adopted Declaration was silent about it – unless we consider the former to be covered in a very general reference that: "The nations of the world must work together […] to lessen pollution of the atmosphere …" [WMO, 1979a].
- Another conference was held in Geneva in November 1979 that concentrated primarily on the problem of transboundary air pollution in connection with the UNECE convention that had just been finalized [CLRTAP, 1979], but several ministers also called attention to the threat to the

[492] We have referred to this issue in a previous study [Faragó, 2016: p. 11]: "The ozone layer issue also became a delicate topic during the preparations for the CSCE, as the discovery of the ozone-destroying effect of the CFCs was published in June 1974 (Molina and Rowland, 1974), and already in December that year, the U.S. House of Representatives held a hearing on this matter."

[493] "Control of air pollution. Desulphurization of fossil fuels and exhaust gases, pollution control of heavy metals, particles, aerosols, nitrogen oxides, in particular those emitted by transport, power stations, and other industrial plants; systems and methods of observation and control of air pollution and its effects, including long-range transport of air pollutants". [CSCE, 1975: p. 28]

[494] Freon-11: trichlorofluoromethane (CCl_3F); Freon-12: chlorofluoromethane (CCl_2F_2).

[495] "The present generation of models predicts that: (a) Continued use of chlorofluoromethanes and nitrogen fertilizers could cause a small long-term depletion in stratospheric ozone; (b) the net effect of SST aircraft might result in a small increase in stratospheric ozone, rather than a decrease as previously predicted". (p. 106)

[496] "In any case, the small number of supersonic transport aircraft likely to fly during the next decade will have no detectable effect on the ozone or the climate." The depletion of ozone by chlorofluorocarbons: "It would be about 25 years before the ozone was depleted by 5 per cent – about the smallest long-term change that could be detected above the natural fluctuations". (p. 140)

ozone layer [Bishop, 1980].[497] (Hungary was represented there by academician Brunó F. Straub, president of the National Council for Environment and Nature Conservation [OKTH, 1980].)

Only the framework for cooperation in the field of observations and research could be agreed upon before 1980 due to the still insufficient knowledge of the causal links related to this hazard and the interests of the countries most involved in freon production, use, and trade.

- At the 1977 Washington conference, initiated by the United Nations Environment Programme and attended by representatives of international organizations and 32 governments, the *Global Plan of Action for the Ozone Layer* was adopted. It aimed at promoting observations and research to better understand the factors influencing the state of the ozone layer, as well as supporting studies that could provide a solid basis for reducing ozone-depleting emissions [UNEP, 1977][498]. Other intergovernmental organizations were also participating in the implementation of this program.[499] They jointly established the Coordinating Committee of the Ozone Layer (CCOL), which held its first meeting in November 1977 and discussed the situation of the 'freon-ozone theory'. (Hungarian academician István Láng, in a book on international environmental protection, mentioned this event held in 1977 and, in connection with it, the issue of the ozone layer [Láng, 1980: pp. 35-37].)
- Based on the new assessments, the role of nitrogen oxides no longer seemed to be significant, and attention turned to potential ozone depletion by freons and halons. As a result of scientific arguments and growing public concern, as mentioned, North American and Northern European countries introduced restrictive measures, initially on spray cans containing freons (as propellant agents).
- Representatives of European countries with a particular interest in the production and use of freons, such as France and Great Britain, continued to argue at an international conference (Munich, December 1978) that the effect of freons on the ozone layer had not been sufficiently proven and therefore opposed the adoption of any specific targets [Stoel, 1979[500]]. The following year, these arguments became even more pronounced, especially on the British side which delegates disputed the depletion of the ozone layer and rejected any even precautionary regulations directed at the use of freons [Allaby, 1979[501]; U.K./DOE, 1979[502]].
- The OECD and the European Economic Community (EEC) were examining the question of restricting the production and consumption of freons and its economic implications. Their experts concluded that although the theory of freons damaging the ozone layer was not sufficiently proven, it might still be justified to consider implementing some preliminary measures. However,

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[497] "Other topics which received special attention during the general debate included toxic substances and toxic wastes, endangered species of flora and fauna, and the threatening impact of fluorocarbons and carbon dioxide on human health and climate." (p. 165)

[498] World Plan of Action on the Ozone Layer: "Quite recently the impact of other substances such as the nitrogen oxides from aircraft exhausts and the man-made chlorofluoromethanes (CFMs) has been receiving intense scrutiny. […] there is a large measure of agreement on the model prediction that current aircraft emissions have minimal effects on the ozone layer but that the effects of continuing emissions of CFMs at the 1973 or higher levels are a matter of concern." (pp. 1-2)

[499] FAO, ICAO, UNEP, UNESA, WHO, WMO; ICC, OECD.

[500] "Hence, the Conference as a whole was able to agree only that "as a precautionary measure, there should be a worldwide reduction in the release" of fluorocarbons." (p. 167)

[501] "In 1979, the British Meteorological Office forwarded a theory that the increased destruction of ozone caused by CFCs was offset by increased ozone creation due to unnaturally high amounts of carbon dioxide, another by-product of pollution, being released into the atmosphere. The equilibrium of creation/destruction of ozone was maintained, and CFC use posed no threat to ozone layer depletion." [Faries, 1990: p. 828]

[502] Foreword by Michael Heseltine (UK secretary of state for the environment) on the theory that CFCs cause ozone depletion: "This theory has been the subject of controversy since it was first propounded in 1974. […] The validity of the hypothesis is still in doubt but if it is right and if emissions were to continue at the earlier levels the threat would increase slightly with each passing year." Conclusions of Part I: "strict regulation is not warranted at present."

to avoid the economic problems arising from these, it would first be necessary to carefully assess which interventions would be possible and how they could be carried out [OECD, 1977; EEC, 1978[503]].

- The World Health Organization (WHO) was no longer concerned only with the health effects of ultraviolet radiation in general, but in the late 1970s, the organization raised the specific question of how anthropogenic damage to the ozone layer would affect the increase in skin cancer [WHO, 1979].[504] The International Radiation Protection Association (IRPA) joined this research program.
- Satellite ozone measurements began in the 1970s. Due to the thorough analysis of data obtained by the Total Ozone Mapping Spectrometer (TOMS) carried on the Nimbus-7 satellite, NASA *could* have contributed to reducing the scientific uncertainty and adopting precautionary political decisions about freons. Very low values of total ozone in the atmosphere were first measured over the Antarctic in 1979 and in the following years, but the data were considered to be *erroneous* measurement results [Lemonick, 1987[505]; Leitze, 2012[506]].
- Although neither model estimates nor observations could adequately support the claim that freons would endanger the ozone layer, the international committee (CCOL) confirmed the likelihood of that risk: "(1) A risk of depletion of the ozone layer due to chlorofluorocarbon releases is still most likely, although in future other halogenated compounds which can reach the stratosphere, require increased consideration. […] (2) If chlorofluorocarbon releases continue at the existing rate, present model calculations estimate an ultimate ozone depletion of about 10 percent" [UNEP/CCOL, 1980]. These conclusions were confirmed in their next report [UNEP/CCOL, 1981], and other experts arrived at similar conclusions: "[T]here is no scientific basis to reject the hypothesis that theoretical model projections of ozone trends are consistent with the observational evidence and to the recognition that there is a threat of a considerable depletion of the ozone layer in the future." [WMO, 1981: par. 21]

These studies about atmospheric ozone also began in Hungary in connection with international observations and research.

- There are references to ground-level ozone measurements carried out as early as the 19th century [Takács, 1970]: "we can read about ozone in the appendix of the first Hungarian-language observation guide, which was published by József Stoczek, a professor at the Technical University of Budapest, on behalf of the academy, in 1861 […]: 'it would be desirable that, in addition to air symptom observations, the ozone content of the free air should also be recorded'. […] In recent

[503] "Notwithstanding the substantial uncertainties attaching to the fluorocarbon-ozone theory as a whole, some of the main components are still unshaken: CFCs are entering the stratosphere where they can cause the depletion of ozone; a thinning of the ozone layer would allow more UV radiation to reach the earth; and UV radiation can be harmful to health." (p. 4) "The main requirement for the industry to make a successful adaptation is time: time to design, procure and install new filling plant; time to develop and test new formulations; time for the ancillary sectors to supply new equipment, components and materials in adequate quantities; and time to complete the investigation of possibilities". (pp. 152-153)

[504] "A series of mathematical models relating human skin cancer incidence to solar UVR has been proposed at various times in the past few years, because of concern about alteration of the stratospheric ozone layer […]. While the uncertainties are very great, the best accepted model data suggest that a 5% increase in erythema-effective solar UVR may result in a 15% (range 7.5-25%) increase in skin cancer in a susceptible population after about 60 years, when a steady state has been reached." (p. 87)

[505] "For several years NASA's scientists failed to accept data on the Antarctic ozone hole that was before their eyes. The reason: computers prescreening data from monitoring satellites had been programmed to dismiss as suspicious presumably wild data showing a 30% or greater drop in ozone levels. After British scientists reported the deficit in 1985, NASA went back to its computer records, finally recognizing that the satellite data had been showing the hole all along."

[506] "Scientists first spotted the ozone hole in 1985, using ground-based sensors to study the Antarctic atmosphere. Earlier data from the Total Ozone Monitoring Satellite (TOMS), a satellite launched in 1979, had shown the same low ozone levels, but because levels were so extremely low, researchers had assumed that the data were incorrect. When they looked at the data again, they confirmed that the hole was real." (p. 15)

decades, we have again encountered spectral observations of upper-atmosphere ozone content at some research sites in Europe, but these modern studies, apart from the similarity of the name, have nothing to do with ground-level ozone from a hundred years ago."

- Measurements of total atmospheric ozone in Hungary began in the second half of the 1960s [Borbély, 1966; Béll & Bucsy, 1970[507]]. The analysis of ozone trends and the presentation of satellite observations were first carried out a decade later [Borbély, 1977; Miskolczi, 1977].
- The theoretical results of that time on ozone were presented by Ernő Mészáros in his books on air chemistry in 1977 and 1981, and then a decade later, he dedicated a separate article to the development of this research, as did Pál Bencze [Mészáros, 1991[508]; Bencze, 1991]. Three Hungarian experts active in the field of chemical research and chemical industry applications, Márton Horváth, László Bilitzky and Jenő Hüttner, discussed the topic of ozone in a monograph in 1976 and also reviewed the knowledge at that time about human interventions affecting the ozone layer in the chapter on atmospheric ozone in the English-language version of their former book, published almost a decade later [Horváth et al., 1985].[509] These publications and the first national observation data contributed to the start of preparations for precautionary measures in Hungary aimed at protecting the ozone layer.

3.2.2. Enough reason to be cautious?

The first global political compromises were made in 1980, even though many still questioned the need for even precautionary measures.

Partial restrictions on the production and use of freons were on the agenda of the UNEP meeting, with the proviso that they would have to be reviewed depending on further scientific studies. These developments may have seemed surprising in light of the doubts and discussions of previous years, but one of the factors behind this was that global production of freons (Freon-11, Freon-12) had already declined for various reasons [Downing & Kates, 1982].[510]

- According to a resolution adopted at the April 1980 meeting of the Governing Council of the United Nations Environment Programme, the global production and consumption of CFCs, in particular, of Freon-11 and Freon-12 should be limited or reduced as a precautionary measure [UNEP, 1980].[511]
- This international development was possible because the Member States of the European Economic Community (EEC) had recently reached an agreement: although they did not reject or confirm the hypothesis of ozone layer damage, they nevertheless undertook not to increase the production capacity of the abovementioned two freons and to reduce their use in aerosol cans by

[507] "In June 1967, regular measurements of ozone began in Budapest (at the Pestlőrinc Observatory)". (p. 19)

[508] "Further studies are of course necessary to definitively clarify these questions. This research is very important, as a deeper exploration of the properties of atmospheric ozone, which is so important for the biosphere and climate, will bring us closer to a better understanding of the impact of humans on the environment." (p. 75)

[509] Effect of human activity on atmospheric ozone. "The most suspicious group of compounds comprises the nitrogen oxides and various halogenated compounds […] this subject cannot be regarded, however, as fully explored due to the complex nature of processes taking place in the atmosphere, with particular regard to stratospheric ozone." (pp. 132-133)

[510] "In late 1977 and early 1978, when Sweden and the United States issued the first restrictions on aerosol usage of CFCs, world production of CFC-11 and CFC-12 was 1550.5 million pounds per year, down from its pinnacle in 1974." (p. 267)

[511] *The Governing Council* "considering that in the present state of scientific knowledge precautionary measures should be taken to limit global production and use, in particular, of the chlorofluorocarbons F-11 and F-12 and that investigations should be pursued into all chlorofluorocarbon emissions; […] Recommends that Governments, especially those of countries where use of the F-11 and F-12 is high, should achieve significant reductions in use".

at least 30% [EEC, 1980].[512] The latter was not an ambitious undertaking, as the amount of freon used for this purpose in the EEC was already nearly this much less than the 1976 level.[513] However, the tightening of these commitments was considered unjustified, both based on existing scientific knowledge and due to the economic consequences, which were considered to be detrimental [EEC, 1980].[514]

- A similar position was reached within the Council of Europe: this meant, on the one hand, acknowledging the potential risk to the ozone layer and in view of this, the need for some initial measures and further research, and on the other, mentioning the adverse socioeconomic effects of restricting the freon applications [CoE, 1980].[515]
- Since it was obvious that the time had not yet come for a binding regulation acceptable to all major freon-producing countries, their representatives – in addition to the already announced restrictions on such propellants in aerosol cans – could only agree on the *voluntary* reduction of freon uses for other purposes and the atmospheric emissions at a forum held at the initiative of the Norwegian government (Oslo, April 15, 1980).

Despite the highly controversial situation, tentative planning for an international agreement began in 1981. This was advocated by countries in which concerns about the threat to the ozone layer had increased among researchers and the public, while representatives of other countries, citing a lack of scientific evidence, continued to oppose the imposition of any international obligations concerning the production and use of these substances.

- Nevertheless, the UNEP Governing Council decided in 1981 that work on a convention for the protection of the ozone layer should begin and entrusted an ad hoc working group of experts (AWG) with its preparation [UNEP, 1981].[516]
- From that time on, four international bodies were engaged in the development and analysis of knowledge on the ozone layer: (i) the Coordination Committee on the Ozone Layer (CCOL); (ii) the group of experts on environmental law of the UNEP (analysis of the relevant existing environmental agreements); (iii) the expert body of the Global Ozone Research and Monitoring Project (GORMP) of the WMO (which also involved representatives of NASA and UNEP) and (iv) the aforementioned working group (AWG). All these activities were carried out at a time when a trend-like decrease in atmospheric total ozone levels could not yet be detected from the measurement data series then available [WMO-NASA, 1981].[517]
- The drafting of the ozone protection convention started and progressed ponderously. The report of the first meeting of the body established for this task described the discussion as follows: "the meeting accepted that there is still uncertainty about the extent to which the ozone layer may be

[512] Article 1: "1. Member States shall take all appropriate measures to ensure that industry situated in their territories does not increase its chlorofluorocarbon production capacity F-11 (CCl_3F) and F-12 (CCI_2F_2). 2. Member States shall take all appropriate measures to ensure that not later than 31 December 1981 industry situated in their territories achieves a reduction of at least 30 % compared with 1976 levels in the use of these chlorofluorocarbons in the filling of aerosol cans."

[513] "With respect to the 30 percent aerosol reduction, European sales of CFCs for this purpose had, by 1980, already declined by over 28 percent from the 1976 peak year." [Benedick, 1989: p. 45]

[514] "At present there is nothing to indicate that CFCs have had a genuine effect on the ozone layer. […] it is difficult to establish a direct quantitative correlation between the decrease of the ozone layer and the incidence of skin cancer." (pp. 8, 11) "A reduction of CFC-11/CFC-12 usage in aerosols going much beyond 30 %·is also likely to cause socio-economic problems in the CFC producing and allied industry sectors" (p. 21)

[515] (5.) "Having taken note of the possible socio-economic implications of controlling the use of chlorofluorocarbons as revealed by OECD studies".

[516] *The Governing Council* "1. Decides to initiate work aimed at the elaboration of a global framework convention for the protection of the ozone layer; 2. Further decides to this end to establish an ad hoc working group of legal and technical experts nominated by interested Governments and intergovernmental organizations".

[517] "Concerning ozone, the leading question is: are there long-term trends at any level which can be plausibly associated with photochemical factors? Although there have been attempts to answer this question for total ozone, the answers are still controversial." (p. 2–42)

depleted […]. However, disagreement was evident and views ranged from a strongly-worded Convention aimed at prohibition of chlorofluorocarbons, to the contention that no Convention was really necessary at this time" [Bojkov, 1982].

- The EEC member states – mainly due to British and French reservations – were willing to support, at most, a 'framework' agreement with general wording and without any concrete targets and obligations, while the members of the 'Toronto Group' were already advocating for an immediate ban on all non-essential aerosol spray applications of freons [Doolittle, 1989: p. 420; Schreurs, 2003[518]]. The participating developing country experts requested the recognition of the specific situation of their country group (e.g., due to their still very low level of per capita CFC use).
- The anthropogenic threat to the ozone layer could not be clearly proven in the next few years either; it was *only* inferred with theoretical models. At the end of 1984, the interagency coordination committee (CCOL) published its summary assessment of the scientific results to date [UNEP/CCOL, 1984], of which Robert T. Watson[519] highlighted, among other things, that "observations of the total ozone column from 1970 to 1980 show no trend. […] There was a statistically meaningful decrease in ozone between 32 and 40 km during the period 1970-1980. Such a decrease is quite consistent with theoretical model predictions for this period, but it should be acknowledged that there are a number of uncertainties in both the observations and the calculations".
- The meetings of the ad hoc working group (AWG) lasted until January 1985. The discussions among the participants and the final draft they produced reflected the situation resulting from the different interpretations of the knowledge available up to that time. The two major interest groups (the group of EEC Member States and the 'Toronto Group') were unable to reach a common understanding on any restrictions on the production, use, and environmental release of CFCs [UNEP/AWG, 1985].[520] For this reason, the regulatory provisions were completely omitted from the draft of the convention at that time, and opinions were extremely divided on the need for a future protocol containing them. Thus, the agenda of the intergovernmental conference held in Vienna (March 18-22, 1985) included only the finalization and adoption of the rather 'soft' *Vienna Convention on the Protection of the Ozone Layer* without any specific CFC-related commitments, but in addition to that, a Resolution on a Protocol Concerning Chlorofluorocarbons was also passed: "The Conference, *Recognizing* the possibility that world-wide emissions and use fully-halogenated chlorofluorocarbons (CFCs) and other chlorine-containing substances can significantly deplete and otherwise modify the ozone layer […] and recognizing at the same time the need to further assess possible modifications and their potentially adverse effects […]. *Determined* therefore to continue negotiations on the development of a protocol to control equitably global production, emissions and use of CFCs". [UNEP, 1985]

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[518] "[T]he Toronto group (the name deriving from the city where a meeting was held by the group), which included Canada, Finland, Norway, Sweden, Switzerland, and the US […] advocated a worldwide ban on non-essential uses of CFCs in spray cans as well as other regulations. […] An EC group, backed by Japan and the Soviet Union, strongly opposed this proposal. […] The EC maintained that a total ban on CFCs in aerosols was jumping ahead of what current science warranted." (p.128)

[519] Robert T. Watson was the US representative of the working group that prepared the convention. He played a major role in shaping US ozone protection policy and the establishment of the international convention. Later, he dealt with the problem of climate change with the same commitment; he was elected the second chairman of the IPCC.

[520] (15.) *Expert from USA*: "Granted that scientific uncertainties were likely to remain for several years, it was necessary to consider what would be the consequences of delay resulting from […] failure to take action now to prevent irreversible damage to the ozone layer." (20.) *Expert speaking on behalf EEC countries*: "if countries had in future to curtail some uses of CFCs that could be accomplished in an orderly manner to minimize economic damage." (29.) *Expert from Canada speaking on behalf of six countries* ('Toronto group'): "He referred to the fact that the existing alternatives for the use of CFCs in refrigeration and foam plastics were costly, whereas for aerosol sprays effective alternatives did exist which were even less costly than CFCs. With regard to the EEC formulation of the control protocol, that approach was not advocated by the six countries".

3.2.3. The great decisive turning point: the discovery of the 'ozone hole'

A decade and a half had passed since Crutzen's 'nitrogen-ozone theory' was published in 1969 and a decade since the 'freon-ozone hypothesis' was proposed in a paper by Molina and Rowland published in *Nature* when Joseph C. Farman, Brian G. Gardiner, and Jonathan D. Shanklin submitted their manuscript on the 'ozone hole' over Antarctica to the same journal in 1984. In detecting this phenomenon, they provided evidence for the existence of anthropogenic ozone layer depletion. Their study appeared in the May 1985 issue of the journal and had a major impact on the continuation of international negotiations with respect to calls for very concrete interventions compared to the rather general goals and only conditional provisions of the ozone protection convention adopted shortly before. A decade later, in 1995, Paul J. Crutzen, Mario J. Molina, and Sherwood F. Rowland were awarded the Nobel Prize in Chemistry in recognition of their scientific work on the ozone layer and its threats.

For a while, researchers failed to recognize the appearance of the 'ozone hole' in their observations from the surface, just as with satellite measurements, because, in both cases, it was initially believed that the unusual values were due to measurement errors.

- During the 1957/1958 International Geophysical Year, a measuring unit of the Global Ozone Observing System (GO_3OS) was installed on an ice shelf in Halley Bay, Antarctica, with the support of the British Antarctic Research Program. It is almost unbelievable that (similarly to the 1979 NASA satellite measurements mentioned above) in the case of the October 1982 observations taken from the surface, the researchers suspected some technical error in the spectrophotometer because the instrument showed the amount of total ozone to be 40% less than the 'usual' average level. When they received the same result over the next two years and rechecked the previous data set, it turned out that this negative trend was valid and had existed since 1977 [Gilet, 2007].[521] This phenomenon was then accepted as fact. The researchers also compared these changes with the increase in atmospheric concentrations of Freon-11 and Freon-12 and arrived at the conclusion that the latter could be the cause of the decrease in the total ozone in the atmosphere [Farman et al., 1985].[522] These findings were confirmed by a review of earlier satellite data (that had also been considered erroneous). Although the 'ozone hole' is also caused by specific upper atmosphere conditions over the Antarctic, ozone depletion was detected elsewhere, too, although to a lesser extent.
- The environmental policy consequences of discovering the 'ozone hole' and confirming the 'ozone-freon hypothesis' may be considered a Eureka Effect (or Eureka Moment) because cooperation on ozone layer protection accelerated after that. We will detail the results of subsequent policy developments in the next section, but here, we recall the assessment of that turning point by two scholars. Diane M. Doolittle put it this way: "Soon after the Vienna

[521] "Joseph Farman had been collecting atmospheric data at Halley Bay, Antarctica since 1957. […]. In 1982, his ozone reading showed a dramatic dip – around 40%. Rather than being alarmed, he was skeptical of the data and thought it must be an instrument malfunction. […] But the following year, Farman still found a drastic decline. He dug up his old data and found that the decline had really started back in 1977. Now Farman suspected that something odd was happening strictly over Halley Bay, leaving other areas unaffected. So the next year, his team took measurements from a location 1,000 miles northwest of Halley Bay. Even there, a large decline in ozone occurred. The mounting evidence was undeniable. Farman decided it was time to publish his data." (pp. 10-11)

[522] "[It is] evident by observations that the spring values of total O_3 in Antarctica have now fallen considerably. […] The present-day atmosphere differs most prominently from that of previous decades in the higher concentrations of halocarbons. Figure 2a shows the monthly mean total O_3 in October at Halley Bay, for 1957-84 […]. Tropospheric concentrations of the halocarbons F-11 ($CFCl_3$) and F-12 (CF_2Cl_2) in the Southern Hemisphere are also shown, plotted to give greatest emphasis to a possible relationship." (pp. 207-208)

Convention was completed, the British scientists published an unexpected finding: there was a hole in the ozone layer over Antarctica. Environmentalists and politicians alike, who weeks before had thought they were well on their way to solving the ozone problem, found that the scientific estimates upon which they based their negotiations were much too conservative. […] Once again, the problem of ozone depletion had been seriously underestimated. A more stringent, multilateral response was clearly needed." [Doolittle, 1989: pp. 421-422] According to Karen T. Litfin: "One outstanding event that […] had an overriding impact on all aspects of the problem, was the discovery of the Antarctic ozone hole, which not only pervaded the psychological and political milieu by heightening the status of scientific uncertainty but strongly influenced the political acceptability of specific modes of framing and interpreting the consensual knowledge at hand. The hole, I will argue, provided dramatic evidence in favor of precautionary action, evidence that participants could not ignore, despite their conscious decision to ignore it." [Litfin, 1994: par. 4]

The new results gave a huge boost to the study of the ozone layer, the international organizational framework of which was developed primarily with the support of the most relevant specialized agencies of the UN. (Institutions such as UNEP and WMO, as well as UNIDO and WHO, in addition to several member organizations of the ICSU.)

- More and more scientists participated in the development of models describing upper atmosphere processes and photochemical reactions that were more consistent with observations, the identification of ozone-depleting synthetic compounds, the exploration of their properties, and the estimation of their atmospheric emissions. The interdisciplinary and international relations of the researchers broadened and intensified, and thus, they were able to better influence and strengthen the policymaking processes aimed at protecting the ozone layer.
- This progress is illustrated well by organizational developments and new reports on this matter. UNEP and WMO initiated the preparation of these reports, and after the adoption of the 1985 convention on the ozone layer (VCPO), other institutions also joined in. The 1986 report already referred to the publication about the total ozone decrease in the Antarctic but also emphasized the remaining uncertainties surrounding the determination of any trends in its values [GORMP, 1986].[523] It was precisely to dispel these doubts and to conduct a more in-depth analysis of the measurement data series of total ozone and upper atmosphere ozone concentration that five organizations institutionalized their cooperation in 1986 by establishing the International Ozone Trends Panel (IOTP).[524] The primary task of this body was to clarify the process and cause of ozone depletion based on the new measurements [IOTP, 1988].[525] The aforementioned inter-organizational committee continued its activity of synthesizing research results, but after the adoption of the ozone convention, in order to create a professional basis for more specific measures. At the 1986 (November) meeting of this committee, the UNEP representative referred to the discovery of the 'ozone hole' as making the formulation of concrete international ozone

[523] "(1) Global trend estimates of total ozone determined from the Dobson spectrophotometer network indicate little overall support for a statistically significant trend during the 14-year period 1970-1983. (2) Recent evidence has been presented that indicates a considerable decrease in Antarctic total ozone during the spring period since about 1968. […] (4) Ozone trend estimates from 13 Umkehr stations indicate statistically significant negative trends from 1970 to 1980 in the middle stratosphere […]. The observational results are sensitive to the inclusion of a term to account for stratospheric aerosol impact on the measurements and the spatial distribution of the sites". (p. 20)

[524] The IOTP was formed by the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), Federal Aviation Administration (FAA), World Meteorological Organization (WMO), and the United Nations Environment Program (UNEP).

[525] "In 1985, two important reports of changes in atmospheric ozone were released. The first report was of a large, sudden, and unanticipated decrease in the abundance of springtime Antarctic ozone over the last decade. The second report, based on satellite data, was of large global-scale decreases since 1979 […]. Ozone Trends Panel, which involved more than 100 scientists, to study the question of whether carefully re-evaluated ground-based and satellite data would support these findings." (p. 3)

protection measures even more urgent [UNEP/CCOL, 1986].[526] (It should be noted that, to some extent, the Intergovernmental Panel on Climate Change was formed in 1988 considering these two institutions – the CCOL and the IOTP – along with the group of scientists who compiled the reports of the GORMP, as models.)

* * *

The decade-long transition (from 1975 onwards) in the scientific recognition and political acknowledgment of the 'ozone problem' was dominated by debate and compromise-seeking between skeptics and those appealing for caution, while – as it soon became clear – the depletion of the ozone layer was already well underway. When and as the 'ozone hole' was discovered and became widely known, the initially cautious and conditional approaches were quickly replaced by much more concrete international goals and measures. The identification of a very clear sign of ozone depletion, the 'ozone hole' over the Antarctic, resulted in a breakthrough in international ozone protection policies and the development and implementation of response measures, which turn of events can be called a 'environmental Eureka Effect'. (The demonstration of the long-range transport of sulfur dioxide emitted into the atmosphere in the case of the 'acid rain' problematic had a similar effect in the first half of the 1980s.) The developments of the aforementioned period are also instructive in a more general sense in terms of the significance and impact on politics of broad research cooperation and correct scientific communication, on the one hand, and of social and technological 'inertia' (the lock-in effect) and economic interests in pursuing certain customary procedures and products, on the other.

3.3. THE THREAT TO THE OZONE LAYER MUST BE ENDED: INTERNATIONAL LEGAL INSTRUMENTS

In the regulatory process of ozone layer protection, four stages can be identified related to the *Vienna Convention for the Protection of the Ozone Layer*, the *Montreal Protocol* (VCPO/MP) and its amendments in accordance with the groups of chemicals included therein – that is, when and for which substances the restrictions were introduced in terms of their production, use, and international trade and of course, in order to control/reduce their environmental releases and harms. These stepwise extensions and gradual phase-out provisions were made by taking into account environmental and health considerations, technological possibilities, and economic factors. With some simplification, the beginnings of these periods of the imposition of freon-related targets and obligations were as follows: (i) the adoption of the international convention on ozone layer protection in 1985 and its protocol in 1987, which inter alia addressed the production and consumption of all chlorofluorocarbons (CFC-regulation period); (ii) the extension of the commitments to 'alternative', less ozone-damaging hydrochlorofluorocarbons from 1992 onward (HCFC-regulation period); (iii) the inclusion of emission reduction requirements for the 'ozone-friendly' but not 'climate-friendly' hydrofluorocarbons, which stage started with the 1997 *Kyoto Protocol*, the implementation of which was supported by the advisory bodies of the *Montreal Protocol* (HFC-regulation period in connection with climate change); (iv) from 2016, the responsibility for controlling the production and consumption of the latter substances was taken over by the Parties to the *Montreal Protocol* through the adoption of a substantial amendment to that legal instrument (HFC-regulation linked to ozone layer protection). Meanwhile, international legal actions against other ozone-depleting materials, such as halons, were also progressing.

[526] "Concern has been heightened by recent discoveries of stratospheric ozone depletion well in excess of predictions by current models. Perhaps, the most attention grabbing has been the 'ozone hole' over the Antarctic. A major campaign to examine this phenomenon indicates that a chemical explanation for the hole is possible, which if so must demand even more priority given to finalizing an effective protocol."

3.3.1. Substances threatening and non-threatening to the ozone layer

The degree of hazard of various chemical compounds in relation to the ozone layer is characterized by their ozone depletion potential (ODP), which is defined relative to this potential of Freon-11 (ODP=1). The chlorine and bromine components of these substances are primarily responsible for the harmful destructuring of ozone molecules in the stratosphere, and their effects are measured in chlorine equivalents (EESC).[527] An important factor in determining this effect is how long, on average, the molecules of such substances reside in the atmosphere and participate as catalysts in the ozone-depletion process.

Products and processes utilizing freons and halons began to replace the less efficient or even dangerous substances previously used worldwide – and have been put to other good uses, as well.

- These synthetic materials have primarily been applied in refrigerators, air conditioning equipment, aerosol sprays, fire extinguishers, and for manufacturing foamed plastics. (A list of such products was approved in 1991, already a few years after the adoption of the *Montreal Protocol*, which import from any State not Party to that legal instrument was banned [UNEP, 2020: p. 35].) Over time, other substances were produced for the same purposes that were less harmful to the ozone layer and transitionally substituted the former. Additionally, other halogenated compounds were found to be beneficial for numerous purposes (e.g., methyl chloroform as a solvent and methyl bromide as a pesticide).
- In the 1980s, these substances were mostly manufactured by chemical plants in a few developed countries (the USA, France, the UK, and Japan). Later, Indian, Chinese, and Russian companies also participated in the production and international trade of significant quantities of these compounds.
- When the threat to the ozone layer was confirmed by more observational data and scientific analysis, it became clear that there should be a complete transition to 'ozone-friendly' chemicals and technologies as soon as possible.

The main groups of substances are listed below that gradually became subject to restrictions aimed at protecting the ozone layer from 1987 onwards [UNEP, 2020].

- ***Chlorofluorocarbons*** (CFCs) are fully halogenated hydrocarbons (halocarbons), sometimes called 'hard freons' whose probably best-known representatives are Freon-11 and Freon-12. Besides carbon atoms, they contain only two types of halogen chemical elements: chlorine and fluorine.[528] In addition to the aforementioned compounds, first three other freons, and then ten more were synthesized and began to be utilized.[529] These substances remain in the atmosphere for a long time (Freon-12 for about a hundred years), and the ozone depletion potential (ODP) of each is the same as or only slightly less than that of Freon-11. For this reason, from 1987 onwards, the direction became increasingly clear – that they should be phased out as soon as possible. Thus, for instance, instead of Freon-12 (CFC-12) and Freon-115 (CFC-115), which were widely used in refrigerating and air conditioning equipment, they were transitionally substituted with a less

[527] Equivalent Effective Stratospheric Chlorine [GORMP, 2010: p. 59].

[528] A halogen element is one that forms a salt when reacts with a metal. This term comes from the Greek words 'hals' (salt) and 'gen' (forming, producing) – like chlorine, which, when it interacts with sodium, forms edible salt (NaCl). From the halogens, the chlorine and bromine are especially harmful to the ozone layer; these are the 'building components' of numerous ozone depleting substances dealt with in this chapter.

[529] Montreal Protocol, Annex A, Group I; Annex B Group I [UNEP, 2020].

ozone-depleting chemical (HCFC-22), and then with a completely 'ozone-friendly' one (HFC-134a).[530]

- ***Hydrochlorofluorocarbons*** (HCFCs) are partially halogenated hydrocarbons (sometimes called 'soft freons'), such as the above-mentioned HCFC-22 or Freon-22. These also contain hydrogen atom(s), making them much less harmful to the ozone layer.[531] More concretely, the ozone depletion potential of most of them is only one-hundredth of that of fully halogenated freons (CFCs). This group includes 40 substances.[532] Among these, the global production of Freon-22 approached one million tons per year about a decade ago.
- ***Bromofluorocarbons*** (BFCs, including Halon-1211, Halon-1301, and Halon-2401). These halons proved to be excellent for fire suppression (i.e., as fire extinguishing agents); however, they are much more harmful than freons when they reach the ozone layer due to the very high ozone depletion potential caused by their bromine atom component.[533]
- ***Hydrobromofluorocarbons*** (HBFCs), for instance, Halon-1201, which was used as a refrigerant and in fire extinguishers. These, like 'soft freons' (HCFCs), are also partially halogenated hydrocarbons that contain a hydrogen atom and are therefore less dangerous to the ozone layer, while some of them have fire-fighting efficiency similar to the above-described halons (BFCs). The group consists of 34 chemicals.[534]
- ***Other ozone-depleting substances***. The ozone-layer protection obligations were gradually extended to some other chemicals. These include, among others: (i) carbon tetrachloride, used for the production of refrigerants and fire extinguishers, and later as a cleansing agent; (ii) methyl chloroform (1,1,1-trichloroethane), employed, e.g., as a solvent; (iii) the fire-extinguishing agent bromochloromethane (or Halon-1011, developed as a replacement for carbon tetrachloride because it turned to be much less ozone-depleting and less toxic); (iv) and methyl bromide (bromomethane or Halon-1001), which is primarily marketed for plant protection purposes (as a fumigant) and as a crop and soil disinfectant.[535]
- ***Ozone-friendly substances***: hydrofluorocarbons (HFCs, for example, Freon-23 and Freon-125) and perfluorocarbons (PFCs). These compounds do not contain either chlorine or bromine atoms, so they are not harmful to the ozone layer. (Their list includes 18 chemicals.)[536] Therefore, these substances seemed to be the most suitable for replacing the more or less ozone-depleting ones. For example, instead of the particularly ozone-depleting Halon-1301 extinguishing agent, the 'ozone-friendly' Freon-125 (HFC 125) proved effective for use in 'sensitive' areas from a fire protection perspective. Some of these compounds also became useful, for example, as refrigerants

[530] The nomenclature or symbols for freons, including CFCs, HCFCs, and HFCs, follows a simple rule: first, the number of C-atoms−1, then the number of H-atoms+1, followed by the number of F-atoms. However, the first number for C-atoms is omitted if it is zero. This rule applies, e.g., to the abovementioned Freon-11, with its chemical formula CCl_3F and Freon-115, with the chemical formula C_2ClF_5.

[531] Due to the hydrogen atom(s) in their molecules, these compounds enter into a chemical reaction in the troposphere with the hydroxyl radical (OH-radical) present there (which is formed in high concentrations under the influence of solar radiation). This means that their atmospheric residence time is much shorter, and consequently, their ozone-depleting effect is much less. In other words, these chemicals are less likely to pass beyond the troposphere, which acts as a 'sink' for them. [Salma, 2012]

[532] Montreal Protocol, Annex C, Group I [UNEP, 2020]; e.g., HCFC-22: $CHClF_2$.

[533] Montreal Protocol, Annex A, Group II: Halon-1211 (ODP=3), Halon-1301 (ODP=10), Halon-2402 (ODP=6) [UNEP, 2020]. The nomenclature or symbols for halons follow a simpler rule: number of C-atoms, number of F-atoms, number of Cl-atoms, and number of Br-atoms. This rule applies, e.g., to Halon-1211 with its chemical formula CF_2ClBr.

[534] Montreal Protocol, Annex C, Group II [UNEP, 2020]; e.g., HBFC-22B1 (CHF_2Br, ODP=0.74).

[535] Montreal Protocol, Annex B, Group II: carbon tetrachloride (CCl_4, ODP=1.1); Annex B, Group III: methyl chloroform (1,1,1-trichloroethane, $C_2H_3Cl_3$, ODP=0.1); Annex C, Group III: bromochloromethane (CH_2BrCl, ODP=0.12); Annex E, Group I: methyl bromide (CH_3Br, ODP=0.6) [UNEP, 2020].

[536] Montreal Protocol, Annex F, Group I; Annex F, Group II [UNEP, 2020].

and others in the electronics industry (semiconductor manufacturing), until problems arose due to their high global warming potential.[537]

3.3.2. Phasing out ozone-depleting substances: science, technology, and politics

To protect the ozone layer, it was necessary to first phase out highly ozone-depleting substances and substitute them, at least temporarily, with compounds that were less harmful in this regard. The commitment to this, i.e., the tightening and expansion of international legal instruments, depended on the even clearer demonstration of a cause-and-effect relationship pertaining to the impairment of the ozone shield and the synthesis and availability of chemicals less hazardous to the ozone layer.

The Vienna Convention for the Protection of the Ozone Layer adopted in March 1985, partly contrary to its title, (i) left open the question of whether there was a threat to the ozone layer and, consequently, (ii) whether the ozone layer needed to be protected at all from human activities that modify it or are *likely* to modify it, and (iii) from adverse effects resulting or only *likely* resulting from the latter [VCPO, 1985].[538] However, it was also pre-indicated how regulation would need to move forward if and when less ambiguous and more precise scientific results became available on this matter in the future.

- It seemed as if nothing had changed since the adoption of the World Plan of Action on the Ozone Layer in 1977 regarding the opinions of those who advocated precaution and those who stressed the lack of scientific evidence of threat to the ozone layer while emphasizing the usefulness of freons [Parson, 2003].[539] According to the resolution adopted in 1985 on possible further specific actions, the negotiations on a future protocol to the just then approved *Vienna Convention* should continue and be supported by a new expert working group (the Vienna Group[540]), although the existence of adverse effects – i.e., the possibility that the emissions of freons concerned would damage the ozone layer – remained to be further clarified [UNEP, 1985].[541] Despite the cautious wording of the 'ozone convention', Alexandre Ch. Kiss believed that its adoption was an important signal for environmental lawyers because it made it clear that they should pay more

[537] Hydrofluorocarbons: for instance HFC-23 (Freon-23) trifluoromethane (CHF_3, GWP=14700 (!)); HFC-125 (Freon-125) pentafluoroethane (C_2HF_5, GWP=3820). Perfluorocarbons: PFC-14 (Freon-14) tetrafluoromethane (CF_4, GWP=7380 (!)); PFC-116 (Freon-116) hexafluoroethane (C_2F_6, GWP=12400 (!)).

[538] Article 2: General obligations "1. The Parties shall take appropriate measures […] to protect human health and the environment against adverse effects resulting or *likely* to result from human activities which modify or are *likely* to modify the ozone layer. 2. To this end the Parties shall […] (b) Adopt appropriate legislative or administrative measures and co-operate in harmonizing appropriate policies to control, limit, reduce or prevent human activities under their jurisdiction or control should it be found that these activities have or are *likely* to have adverse effects resulting from modification or *likely* modification of the ozone layer".

[539] 5.2. International negotiations leading to the Vienna Convention, 1982-1985: "The Vienna Convention represented an exhausted compromise containing no substantive provisions beyond those agreed in 1977 plan of action. […] The Convention offered so little concrete benefit that the strongest argument the U.S. State Department could find to urge a favorable Senate vote was that it might encourage the Soviet Union finally to release their CFC production data."

[540] Vienna Group: Ad Hoc Working Group of Legal and Technical Experts for the Preparation of the Protocol on Chlorofluorocarbons.

[541] "Recognizing the possibility that world-wide emissions and use of fully-halogenated chlorofluorocarbons (CFCs) and other chlorine-containing substances can significantly deplete and otherwise modify the ozone layer […], and recognizing at the same time the need to further assess possible modifications and their adverse effects". (p. 7)

attention to international environmental problems that cannot be solved by traditional legal means [Kiss, 1985].[542]

- In the spirit of compromise, the *Vienna Convention* nevertheless stipulated that substances that could potentially affect the ozone layer should be examined and that restrictions on their production and use, or their replacement with other substances, should be considered. The potentially harmful chemicals included the Freon-11 and Freon-12, some 'soft freons' (HCFCs), and among the halons, for example, Halon-1301.[543]

By ordering the events referred to above chronologically, the significance of the discovery of the ozone hole as a turning point in the initial process of the formulation of international response policies can be better understood.

- Farman and his colleagues submitted a manuscript on the 'ozone hole' to the journal *Nature* in November 1984.
- The negotiations that prepared the convention on ozone layer protection (with very conditional provisions) were completed in January 1985.
- It is likely that the discovery of the 'ozone hole' was not even known to the government delegations when the Convention was adopted in March 1985, as the aforementioned scientific communication was published on May 16, 1985 [Farman et al., 1985].
- Presumably still regardless of the new scientific findings, the UNEP decision urging the development of the protocol on freons was passed on May 24, 1985: "The Governing Council, […] Notes the efforts of the Executive Director and the Co-ordinating Committee on the Ozone Layer [CCOL] to gather data on the production, release and use of chlorofluorocarbons and other halocarbons which may cause ozone layer modification …".[544]
- Then, at the very beginning of 1986, the new report (*Atmospheric Ozone 1985*) was issued, which already included the statement (as mentioned in the previous section) that "Recent evidence has been presented that indicates a considerable decrease in Antarctic total ozone during the spring period since about 1968", the obvious source of which was the article published in *Nature* and referred to at the very end of this voluminous report [GORMP, 1986: p. 20, p. R-21].
- To all this, it is worth adding the report finalized in May 1986 that was compiled by NASA scientists and which also took into account the various analyses and observations that had been made until that time, among the latter the results of the recent Antarctic measurement time series: "the ground-based observations of the British Antarctic Survey that there has been an approximately 40% decrease in total column ozone over Antarctica during the spring period since the mid-1970s". [Watson et al., 1986: p. 10]

International negotiations on ozone layer protection entered a new phase from 1986 onward, first addressing substances with high ozone-depleting potential, followed by dealing with the partially

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[542] "Les récents développements concernant la protection de l'atmosphère, voire de la stratosphère interpellent les juristes. Dans l'ensemble, on a l'impression d'un certain retard du droit par rapport aux réalités écologiques. Pourtant, aucun domaine juridique ne s'est développé aussi rapidement au cours des dernières décennies que le droit de l'nvironnement. Sans doute doit-on rattraper une longue période d'ignorance et d'insouciance où seul comptait la production de biens. […] Toutefois, le droit traditionnel est aussi désemparé devant les phénomènes où les liens de causalité entre actes polluants et effets de pollutions ne peuvent être établis que sur un plan collectif, sans que le mécanisme habituel règle-infraction-responsabilité puisse jouer." (pp. 821-822)

[543] Annex I "4. The following chemical substances of natural and anthropogenic origin, not listed in order of priority, are thought to have the potential to modify the chemical and physical properties of the ozone layer. […] (c) Chlorine substances. (i) Fully halogenated alkanes, e.g., CCl_4, $CFCl_3$ (CFC–11), CF_2Cl_2 (CFC–12), $C_2F_3Cl_3$ (CFC–113), $C_2F_4Cl_2$ (CFC–114). […] (ii) Partially halogenated alkanes, e.g. […] CHF_2Cl (CFC–22), CH_3CCl_3, $CHFCl_2$ (CFC–21). […] (d) Bromine substances. Fully halogenated alkanes, e.g. CF_3Br."

[544] First section of the decision 13/18 by the UNEP/GC on the 'Protection of the ozone layer' (Annex to the UNEP/GC report on its 13th session, pp. 51-52).

halogenated freons and other ozone-depleting substances in order to gradually foster the transition to the production and consumption of completely 'ozone-friendly' compounds.

- We have mentioned other major developments in scientific cooperation that followed the adoption of the *Vienna Convention* within a short period of time (UNEP/CCOL, 1986; IOTP, 1986). Thanks to these, events accelerated from the end of 1986 to such an extent that the 'Vienna Group' finalized the text of the additional legal instrument within nine months, which was approved by the government representatives on 16 September 1987 at a conference held in Montreal. During the preparatory process, the debate was no longer about the threat to the ozone layer (since that was already recognized as a fact) but about which ozone-depleting substances should be restricted in their production, use, and international trade as soon as possible and to what extent. Based on a 1994 UN General Assembly resolution, the day of the adoption of the *Montreal Protocol on Substances That Deplete the Ozone Layer*, that is, 16 September, became the International Day for the Preservation of the Ozone Layer, or the 'World Ozone Day'.[545]

- The *Montreal Protocol* contained quantified obligations concerning the halogenated compounds that were most widely produced and consumed at the time: it required (i) such reductions for five types of freons (by 1999, a 50% reduction in the amount compared to the 1986 level), and (ii) at least, the avoidance of an increase in production and use of three types of halons for a few years [VCPO/MP, 1987].[546] These provisions aimed at restricting the cumulative ozone-depleting effects of these substances. The specific situations of developing countries were taken into account, as most of them did not produce such chemicals, and their per capita consumption was low.

- The anthropogenic causes of changes in the ozone layer became even more evident from the new international assessment reports, and the scenarios regarding the implications of ozone layer depletion also had their impact in terms of further strengthening international collaboration and policy responses [IOTP 1988[547]; GORMP, 1989, 1991[548]; UNEP, 1989, 1991]. The scientific committee of ICSU dealing with environmental problems decided to participate in these research activities at its meeting held in Budapest [ICSU/SCOPE, 1992].[549] (That meeting was held in the Hungarian capital at the invitation of Györgyi Rontó, Professor of Semmelweis University and József Tigyi, Secretary General of the ICSU/IUPAB.)

- The warnings at the time about the harmful health effects directly caused by these chemicals should also be highlighted. "Chlorofluorocarbon propellants and solvents may present a hazard for human beings by inhalation, ingestion, and dermal absorption." [WHO/IPCS, 1990: p. 36] "The toxicological information on HCFC 141b, HCFC 123 and HCFC 124 are incomplete and more data are required before an evaluation of the human health hazard can be made. Both HCFC 133a and HCFC 132b pose a hazard to human health." [WHO/IPCS, 1992: p. 13]

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[545] The most important international- and national-level developments related to ozone layer protection were summarized by Hungarian expert Róbert Tóth in an article on the history of the World Ozone Day (Légkör, 1998/03, pp. 7-10).

[546] Annex A - Controlled substances. Freons: CFC-11, CFC-12, CFC-113, CFC-114, CFC-115; Halons: Halon-1211, Halon-1301, Halon-2402.

[547] Changes in total column ozone: "The observed changes may be due wholly, or in part, to the increased atmospheric abundance of trace gases, primarily CFC's." (p. 4)

[548] "Recent laboratory research and reinterpretation of field measurements have strengthened the evidence that the Antarctic ozone hole is primarily due to chlorine- and bromine-containing chemicals. In addition, the weight of evidence suggests that the observed middle and high-latitude ozone losses are largely due to chlorine and bromine. Therefore, as the atmospheric abundances of chlorine and bromine increase in the future, significant additional losses of ozone are expected at middle latitudes and in the Arctic." (p. xi)

[549] "The purpose of the workshop was twofold: (a) to discuss the current state of knowledge of the effects of the thinning of the stratospheric ozone layer on terrestrial plants, aquatic systems, animal and human health, and biogeochemical cycles, as well as the instrumentation used to monitor and measure UV-B radiation, and (b) to draft a research plan to implement the research priorities in these areas of investigation." (p. 8)

"Although HCFC 21 poses a low environmental and indirect health risk, it is not recommended as a substitute for the chlorofluorocarbons included in the Montreal Protocol because of possible direct health risk due to its liver toxicity." [WHO/IPCS, 1991: p. 11] These findings further reinforced the need for more decisive measures.

- As concerns the already at least partially regulated ozone-depleting substances, the experts strongly recommended a further reduction in their emissions and even the full elimination of their use as soon as possible.[550] At the World Summit on Sustainable Development in June 1992, there was also consensus on this issue: "the total chlorine loading of the atmosphere of ozone-depleting substances has continued to rise"; "consider further actions that prove warranted and feasible on the basis of these assessments" [UN, 1992: par. 9.22 and par. 9.24.c].
- As a consequence, the commitment to entirely phase out all CFCs, the three highly ozone-destroying halons, carbon tetrachloride and methyl chloroform, strengthened. This was reflected in the 1990 London and 1992 Copenhagen decisions of the Parties to the *Montreal Protocol*, which required the production and use of these halons to be phased out from 1994 and the other substances mentioned above from 1996 (with some exceptions).[551] Developing countries were allowed to fulfill these obligations several years later, and a financial institution, the Multilateral Fund for the Implementation of the Montreal Protocol, was established to support them in this regard.
- Other international organizations (UNDP, UNIDO, WB) supported related research and development projects as well as facilitated the transfer of relevant technologies primarily to numerous developing countries in order to accelerate the elimination of the use of ozone-depleting substances. However, both compliance with the restrictive regulations and the contribution to the aforementioned financial fund caused serious difficulties for most Central and Eastern European countries with 'economies in transition' [UNEP, 1996[552]; Faragó, 2012].
- With many applications, compounds with less ozone depletion potential were needed as a first step to decrease the hazardous effects on the ozone layer. In the case of aerosol propellants, the very first freons (CFCs) were relatively quickly phased out and substituted (except for in some medical and other forms of utilizations). Regarding the cooling agents, the transition to new (alternative) refrigerants turned out to be a more complicated problem. It therefore became essential at least to prevent the freons used in them from being released into the atmosphere during the repair or disposal of such devices. International institutions, such as a Paris-based one specializing in refrigeration technology that was founded in 1920, took an active part in these research, innovation, and development (RID) activities.[553] Replacing methyl bromide, which was widely used in agriculture, and substituting the halon agent used in portable fire extinguishers on aircraft seemed to be particularly difficult tasks [Tapscott, 1992].[554]

Less ozone-depleting freons and halons (partially halogenated hydrocarbons, HCFCs, and HBFCs) were intended only as temporary substitutes for their 'predecessors', which were already destined for complete phase-out. However, restrictions on the production and consumption of the former compounds also began in 1992.

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[550] "Lowering the peak and hastening the subsequent decline of chlorine and bromine levels can be accomplished in a variety of ways, including an accelerated phase-out of controlled substances and limitations on currently uncontrolled halocarbons." [GORMP, 1991: p. xvii]

[551] Adjustments and Amendments to the Montreal Protocol: London, 1990, Copenhagen, 1992.

[552] A working group of an expert panel associated with the Montreal Protocol (TEAP) examined the situation of these countries between 1994 and 1996 and made recommendations concerning how to assist them to meet the requirements stemming from the Protocol. Employees of the then Ministry of Environment (Hungary), László Dobó (co-chair) and Róbert Tóth were members of this group.

[553] International Institute of Refrigeration / Institute International du Froid.

[554] In these and other particularly 'sensitive' locations, Halon-1301 and Halon-1211 became temporary substitutes for firefighting, which were later replaced by the 'ozone-friendly' (but not 'climate-friendly') HFC-134a fire-extinguishing agent.

- Expert bodies were established under the auspices of the *Montreal Protocol* to monitor the ozone depletion process and identify possible further ozone protection interventions. These included the Scientific Assessment Panel (SAP), the Environmental Effects Assessment Panel (EEAR), and the Technology and Economic Assessment Panel (TEAP), which periodically summarized the most important new scientific and technological results for policymakers. Other expert groups dealt with specific issues, such as the committee assessing the possibilities of replacing halons (Halons Technical Options Committee).
- The international scientific cooperation previously established by UNEP and WMO continued, and through this, assessments of the worsening situation of the ozone layer were made recurrently – that is, in 1994, 1998, and then in 2006. The latter report indicated that the decline in upper-atmosphere ozone concentrations had halted, while the atmospheric emissions of the ozone-depleting freons were still increasing, so the 'healing' of the ozone layer was expected to take place later than previously estimated [GORMP, 2006].[555] The obvious conclusion from this and other expert bodies' findings was that the use of chemicals applied as temporary alternatives must also be abandoned at an accelerated pace.
- The international regulatory period applicable to substances intended to substitute the initially introduced freons and halons (with high ozone depletion potential) in the interim lasted for a decade and a half. The negotiators first addressed these less but still ozone-threatening compounds at a meeting in 1992 in Copenhagen and agreed on the first restrictive provisions (i.e., this was the beginning of the 'HCFC-regulation period'). This topic was on the agenda of the subsequent meetings held in 1995 (Vienna), 1997 (Montreal), 1999 (Beijing), and 2007 (Montreal). In 1995, it was stipulated that the alternative bromine compounds (HBFCs, such as the Halon-1201), substituting the previously introduced highly ozone-damaging halons, should not be produced and consumed from 1996 onward. Then, in 2007, it was agreed that the 'soft freons' (HCFCs) should also be phased out from 2020 (while the developing countries were permitted an additional decade to fulfill this obligation, and some exceptions were also accepted, e.g., for 'essential use' and 'basic domestic needs'). Furthermore, it was decided to terminate the application of bromochloromethane (Halon-1011), used as a fire extinguisher, by 2002, and of methyl bromide, a crop and soil disinfectant, by 2015. (The latter was used at an annual rate of about seventy thousand tons in the late 1990s.)

In Hungary, the ozone layer problem received greater attention from the late 1980s onward,[556] which was also reflected in the country's accession to the *Vienna Convention* in 1988 and to the *Montreal Protocol* a year later.

- Domestic observations and analyses by national experts confirmed that dangerous changes in the ozone layer were underway [Loksa, 1991[557]; Bozó, 1991; Rontó et al., 1993[558]; Tóth, 2000; Faragó, 2001]. Then, more and more scientific publications started to deal with this global environmental issue and the expanding international cooperation and stressed the importance of getting involved in it [Kerényi, 2003: pp. 323-330; Tóth, 2007; Haszpra, 2011a; Salma, 2012;

[555] "Long-term recovery of the ozone layer from the effects of ozone-depleting substances is expected to span much of the 21st century and is estimated to occur later than projected in the previous Assessment (2002). […] This projected later date primarily results from (i) an increase in CFC-11 and CFC-12 emissions due to the larger recent estimates of amounts currently contained in equipment and products (banks) and (ii) an increase in HCFC-22 emissions due to larger estimated future production". (p. xxxv)

[556] In the 1987 article "Hole in the Earth's Ozone Layer", Éva Gajzágó summarized the key scientific results at the time about the threat to the ozone layer and the objectives of the Montreal Protocol (*Élet és Tudomány*, 49., 1539-1541).

[557] "[At the Budapest ozone measuring station] no direct decrease is observed in the 20-year data series of total ozone content. However, the negative trend in April indicates a smaller ozone decrease. It seems likely that such changes will be registered to an increasingly significant extent in the peripheral areas of the Arctic, and thus possibly in Central Europe as well." (p. 109)

[558] "In the temperate latitudes, only a rather slow ozone decrease occurred in the 1970s and 1980s. Over Hungary, the rate of decrease was 1.7% per 10 years. At the beginning of 1992, this situation changed dramatically, and a permanent ozone deficiency of around 10 percent compared to the previous ozone level developed." (p. 4)

Homonnai et al., 2013; Várai et al., 2015; Antal, 2016; Faragó, 2016]. Special emphasis was placed on the health hazards resulting from elevated levels of ultraviolet radiation [Páldy, 2016; Antal, Páldy & Tóth, 2019].

- All of this led to the call for the effective fulfillment of international requirements [Rontó et al., 1993: p. 12; Faragó, 2002; Nagy et al., 2003; Tóth, 2005]. In addition to the regulatory instruments (starting with a ministerial decree in 1993),[559] tasks associated with ozone-layer protection became part of national environmental protection programs, including the first one [NKP-1, 1997], as well as the most recent fifth program [NKP-5, 2022].[560] The implementation of the commitments – including the disposal of freons and halons from refrigerators or fire extinguishers taken out of service – was supported by the Global Environment Facility [Dobó et al., 1998; Pató & Faragó, 2004].[561]

It seemed that by 2030, the history of threats to the 'ozone shield' might come to an end, at least with the final cessation of the anthropogenic activities that had directly led to this.

- The fundamental condition for this was and remain that all countries accept and comply with the increasingly strict provisions of the *Montreal Protocol*, and accordingly, the transition to chlorine- and bromine-free 'ozone-friendly' chemicals should continue everywhere at the agreed pace.
- It was an encouraging sign that at the turn of the millennium, the first signs of 'healing' of the Antarctic ozone layer were observable [Solomon et al., 2016].[562]

3.3.3. Solving the 'ozone problem' while exacerbating another global environmental hazard?

During the negotiations about the agreements on protecting the ozone layer, it was raised that the chemicals controlled by them have also major effects on the climate system, as all of them are characterized by high global warming potential (GWP). But, for a long time, the international regulations on ozone-depleting substances focused exclusively on terminating the threat to the ozone layer from human activities, depending primarily (i) on the synthesis of substitute (alternative) compounds that are less or not at all harmful to the ozone layer, and (ii) the economic and technical conditions for their production and marketing in sufficiently large volumes. These efforts, however, contributed to the intensification of another dangerous process, the control or even containment of which became the objective of the 1992 *UN Framework Convention on Climate Change*.

The contribution of ozone-depleting substances and ozone itself to the greenhouse effect has been known for a long time, and the more thorough consideration of this has been an issue since the 1970s.

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[559] The accession to these international agreements was followed by the regulations necessary for their implementation, starting with a ministerial decree (Decree 22/1993 of the Ministry of Environment and Regional Development), which provisions were reinforced and expanded with a government decree on substances that deplete the ozone layer, covering their production, international trade, use, recovery, recycling, regeneration, and disposal (Government Decree 94/2003).

[560] "AIR-6: (c) Phasing out the use of ozone-depleting substances by meeting the deadlines agreed in the conventions." [NKP-1, 1997] "Complete reduction of the use of ozone-depleting substances; prevention of ozone-depleting substances in products and equipment from entering the atmosphere; reduction of the amount of hydrofluorocarbons (HFCs) by 79% between 2015-2030." [NKP-5, 2022] (p. 106)

[561] Global Environment Facility: "Hungary Phase-out of Ozone Depleting Substances Project" (1995-1998). The author of this book became the coordinator of national cooperation with this international organization from 1993 onwards and, with appropriate authorization, participated in the sessions of the GEF Council and General Assembly until 2010.

[562] "Industrial chlorofluorocarbons that cause ozone depletion have been phased out under the Montreal Protocol. […] Observations and model calculations taken together indicate that the onset of healing of Antarctic ozone loss has now emerged in September. Fingerprints of September healing since 2000 are identified" (p. 269).

- The global program that marked the beginning of cooperation on the ozone layer already identified the need to study the effects on the climate of atmospheric 'ozone changes' and ozone-depleting substances [UNEP, 1977].[563] The expert committee established to assess the state of the ozone layer confirmed that the above effects should also be taken into account while preparations for the future convention for the protection of the ozone layer were already underway [UNEP/CCOL, 1983].[564]
- After the adoption of the *Vienna Convention* and its *Montreal Protocol*, during the negotiations on possible stricter obligations (amendments and adjustments), there was even more talk about the potential climate-modifying role of freon and halon emissions [UNEP/CCOL, 1986; GORMP, 1989]. Yet, this remained a secondary consideration for a long time because concerns about the 'thinning' of the ozone layer and the harmful effects of increasing ultraviolet radiation made preserving the ozone layer the priority.[565] In addition, this approach was motivated by the fact that the decrease in atmospheric ozone (itself a potent greenhouse gas) had somewhat offset the strengthening climatic effect of ozone-depleting substances and other greenhouse gases increasingly released into the atmosphere.[566]

For almost a quarter of a century, climate policy agreements and decisions regulated the production and consumption of ozone-depleting compounds and their substitutes not yet controlled by the *Montreal Protocol*. During this long period, the various bodies of the two global environmental agreements were in working contact, but the climate-changing 'side effects' resulting from the global ozone problem and its phased treatment were transferred into the realm of climate policymaking.

- The draft and then the final version of the *Vienna Convention for the Protection of the Ozone Layer* referred to 'climatic effects' and their examination in the future [UNEP/AWG, 1985[567]; VCPO, 1985[568]]. The *Montreal Protocol*, approved two years later, very briefly mentioned this issue as well [VCPO/MP, 1987].[569]
- Ever since negotiations on the future climate change convention began with a 1988 UN resolution, and the activities of the intergovernmental panel (IPCC) established that year, the 'climatic effects' of chemicals controlled by the *Montreal Protocol* were recurrently on the agenda at ozone protection meetings. More concretely, the Meeting of the Parties passed two essential decisions in that regard, according to which the Scientific Assessment Panel (SAP) in 1989 and the Technology and Economic Assessment Panel (TEAP) in 1992 (a few months after the adoption of the climate change convention) were tasked with assessing the global warming effects of ozone-depleting substances.[570]
- By a strange coincidence, in 1992, two further international decisions were made involving some completely opposing goals: (i) in order to protect the ozone layer, the regulation on the partially

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[563] Effects on climate. "Further develop modelling capacity to assess the effects of ozone changes and also those CFMs and other compounds with similar effects on the earth's radiation balance and the global climate." (p. 8)

[564] Ozone effects on climate: "Several of the trace gases which effect stratospheric ozone photochemically […] enhance the greenhouse effect, and may lead to surface warming." (p. 13)

[565] "A systematic environmental evaluation of replacements for fully halogenated chlorofluorocarbons (CFCs) includes the potential effects of each replacement chemical on global warming. While the major focus for rising environmental concerns centers on the potential effects of long-lived CFCs on stratospheric ozone, the role of these gases as contributors to an enhanced greenhouse or global warming also needs examination." [GORMP, 1989: p. 385]

[566] Ozone and Climate Relations: "the ozone depletion may indeed have offset a significant fraction of the radiative forcing due to increases of all greenhouse gases over the past decade." [GORMP, 1991: p. xi]

[567] "The Parties to this Protocol […] Recognizing also the potential climatic effects of chlorofluorocarbon emissions …".

[568] Adverse effects: "means changes in the physical environment or biota, including changes in climate"; Research and systematic observations: "1. The Parties undertake, as appropriate, to initiate and co-operate in […] the conduct of research and scientific assessments on: […] (c) Climatic effects deriving from any modifications of the ozone layer".

[569] The Parties to this Protocol "Conscious of the potential climatic effects of emissions of these substances …".

[570] Montreal Protocol, Meeting of the Parties (MoP): Decision I/10 (1989) 'Characteristics of relevant substances'; Decision IV/13 (1992) 'Assessment panels'.

halogenated 'soft freons' (HCFCs) to be gradually replaced by chlorine-free 'ozone-friendly' freons (HFCs), and (ii) the convention on climate change, whose emission control provisions were to be applied to those 'ozone-friendly' substances as well [UNFCCC, 1992].[571] So, the latter compounds came under the scope of this new legal instrument because, although they represented an optimal solution in terms of ozone layer protection, they were powerful greenhouse gases. To put it even more clearly, in accordance with the *Copenhagen Amendment to the Montreal Protocol* (adopted in November 1992), the 'soft freons' are to be phased out by 2030 and substituted with non-ozone-depleting substances, the emissions of which should be controlled in correspondence with the *UN Framework Convention on Climate Change* (which text was completed in May 1992).

- In this highly controversial situation, the 1997 *Kyoto Protocol* brought a new turn. Following its adoption, the representatives of the *Montreal Protocol* initiated cooperation between the governing and expert bodies of the two international agreements in 1998, especially concerning those 'ozone-friendly' compounds that were considered the most promising alternatives to some ozone-depleting substances for the protection of the ozone layer but which were very much not 'climate-friendly'.[572] These consultations mainly took place between the ozone layer protocol's Technology and Economic Assessment Panel (TEAP) and the climate convention's Subsidiary Body for Scientific and Technological Advice (SBSTA).[573] (The TEAP also contacted the IPCC and one of the results of this collaboration was the joint assessment report of the IPCC and TEAP on chemicals of concern regarding both the ozone layer and climate protection [IPCC & TEAP, 2005].) Nevertheless, all these efforts did not change the fact that the problem of a substantial 'side effect' resulting from the solution of one global problem was transferred to an intergovernmental institutional system dealing with another global environmental problem.
- The provisions of the *Kyoto Protocol* covered groups of 'ozone-friendly' substances produced and used for a variety of purposes as the best alternative compounds in line with the objective of the ozone layer protection agreement [UNFCCC/KP, 1997].[574] The same arrangements were repeated in the 2012 *Doha Amendment to the Kyoto Protocol* and the 2015 *Paris Agreement* concerning the reduction of greenhouse gas emissions "not controlled by the Montreal Protocol" [UNFCCC/DA, 2012; UNFCCC/PA, 2015].
- It was first raised in 2009 at the meeting of the Parties to the *Montreal Protocol* that hydrochlorofluorocarbons (HCFCs) ought to be gradually replaced with both 'ozone-friendly' *and* 'climate-friendly' substances [VCPO/MP, 2009].[575] In 2012, prominent scientists urged a restriction on the use of all freons with strong global warming potential [Velders et al., 2012].[576]

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[571] Article 4: Commitments. "(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol".

[572] Montreal Protocol, MoP: Decision X/16 (1998) Implementation of the Montreal Protocol in the light of the Kyoto Protocol: "the relevant Montreal Protocol bodies, within their areas of competence: (a) To provide relevant information on HFCs and PFCs […] (d) To otherwise continue to cooperate with the relevant bodies under the United Nations Framework Convention on Climate Change and IPCC on these matters".

[573] The author of this book (as the first chair of the advisory body established under the UN Framework Convention on Climate Change) closely cooperated with Lambert Kuijpers (NL), who was the vice-chair and then co-chair of the Montreal Protocol's panel (TEAP) on the interrelated problems of climate change and ozone layer depletion.

[574] Annex A of the Kyoto Protocol listed the greenhouse gases under the scope of this legal instrument, including the hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

[575] "Concerned that climate change is occurring faster than previously predicted […]. Emphasize the fact that the substitution of hydrochlorofluorocarbons (HCFCs) need not necessarily rely on the use of high-GWP alternatives […]. Agree to take appropriate measures to limit the use of high-GWP alternatives to ODSs as soon as practicable."

[576] "Given that climate impacts of HFC use can be viewed as unintended side effects of the Montreal Protocol, an option is to expand provisions of this protocol […], such an approach could effectively and quickly limit continued growth of high-GWP HFCs and preserve the substantial climate benefits that were gained by the Montreal Protocol in phasing out ODSs." (p. 923)

This was also agreed upon at the then UN Conference on Sustainable Development [UN, 2012: par. 222]: "We recognize that the phase-out of ozone-depleting substances is resulting in a rapid increase in the use and release of high global warming potential hydrofluorocarbons to the environment. We support a gradual phase-down in the consumption and production of hydrofluorocarbons."

The 2016 amendment to the *Montreal Protocol* eventually set the goal of protecting the ozone layer and the climate simultaneously, thus putting an end to the ambivalent situation according to which the elimination of the use of ozone-depleting substances would lead to the aggravation of another dangerous environmental process [Heath, 2017; Faragó, 2017; Birmpili, 2018[577]; Solomon et al., 2020[578]].

- In line with the *Kigali Amendment* [VCPO/KA, 2016], the production and consumption of hydrofluorocarbons (HFCs), which are excellent for protecting the ozone layer but potent greenhouse gases, must be limited from 2019 onwards. More specifically, the developed countries were obliged to achieve in this regard an 85% reduction within two decades, and developing countries an 80-85% reduction within one more decade (although compared to different reference levels). Without this, the use of 'ozone-friendly' freons would presumably continue to grow rapidly, primarily in refrigeration and air conditioning equipment, the atmospheric emissions of which would significantly offset the global reduction in emissions of other greenhouse gases and their climate change mitigation effects expected under the *Paris Agreement*.
- Consequently, the need to transition to substances and technologies related to a wide range of products and industrial processes that do not, or to a much lesser extent, hinder the solution of both ozone layer depletion *and* climate change problems was at last acknowledged.

* * *

International legal instruments containing progressively strict obligations have been adopted to protect the ozone layer. Observations and scientific analyses that increasingly accurately revealed dangerous ozone layer depletion and its causes, as well as the 'ozone-friendly' technological developments, were essential in these achievements of international policy cooperation. In addition, (even if after a long time) the management of the two interlinked, human-induced global environmental problematics – which for simplicity can be called the 'ozone versus climate' conflict – will hopefully be finally and successfully concluded, provided that the 'ozone- *and* climate-friendly' policy responses do not inadvertently generate another significant environmental hazard.

3.4. THE EFFECTIVENESS OF SCIENCE AND POLICY COOPERATION: WILL THE OZONE LAYER BE SAVED?

As a result of internationally agreed interventions, the trend to the depletion of the ozone layer in the upper atmosphere has halted since the end of the 1990s. However, according to scenarios based on various assumptions, it may take several decades before the level of ozone there returns to its previous stable state that protects life on Earth from harmful ultraviolet solar radiation.

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[577] "[I]n 2016 the parties agreed to amend the Protocol […]. Phasing down HFCs may avoid up to 0.5 degrees Celsius of temperature increase by the end of the century". (p. 427)

[578] "HFCs were introduced into the economy mainly as non-ozone-depleting substitutes for CFCs, but are potent greenhouse gases. As emissions increased, governments pondered whether it was best to control them under the climate treaty, which was responsible for greenhouse gases, or under the Protocol, which was the catalyst for HFC use in the first place. The result was the Kigali Amendment of the Montreal Protocol agreed to in 2016, which levied much more stringent controls of HFCs than were possible under the current climate treaty". (p. 3)

3.4.1. Phasing out the ozone layer depleting substances: the initial difficulties

Curbing ozone layer 'thinning' and then its recovery depend on the extent and pace of reducing the production, consumption, and atmospheric emissions of ozone-depleting substances. It is precisely for this purpose that the provisions of the 1985 ozone protection convention and its 1987 protocol, as well as the latter's adjustments and amendments, were adopted. However, their adequacy and effectiveness depend on numerous compromises (accepted for various reasons) and the actual fulfillment of the obligations inscribed within them.

- When Molina and Rowland first raised awareness of the possibility of the escalating ozone layer depletion due to atmospheric releases of CFCs, their calculations were based on the expected future production volumes of these chemicals [Molina & Rowland, 1974]. Their claims were readily comparable with a much later hypothetical estimate, the authors of which examined what would happen if the *Montreal Protocol* (along with the regulations extending and tightening its provisions) did not exist [Newman et al., 2009].[579] The 'what the world avoided' scenario in this study projected that total column ozone in the atmosphere would decrease by about a third on a global average, leading to an extreme increase in ultraviolet radiation reaching the surface. Fortunately, however, the control and reduction of the use and emissions of ozone-depleting substances began in 1985.
- To verify the political intention/commitment to protect the ozone layer on the part of a country, one of the first steps is to clarify whether its government decided to participate in the implementation of the relevant international programs and agreements. In the case of an international legal instrument, of course, this means becoming a Party to it (e.g., by ratifying the agreement concerned). Sooner or later, all States became Parties to the 1985 *Vienna Convention*, its 1987 *Montreal Protocol,* and all amendments to the latter adopted until the turn of the millennium. These decisions by developing countries were facilitated by compromises that permitted them to implement the restrictive measures regarding the ozone-depleting substances by later deadlines than developed countries. Further, they could request financial support from the Multilateral Fund to fulfill those and some other related obligations. Even under these conditions, many developing countries were only ready to undertake the additional and more difficult-to-implement requirements more than a decade after they were adopted by the Parties to the *Montreal Protocol* in 1997 and 1999.
- The situation became even more complicated concerning the 2016 *Kigali Amendment*, which calls for a transition to substances that neither deplete the ozone layer nor contribute to the enhancement of the atmospheric greenhouse effect: one-fifth of States are not yet Party to this, and to some extent, this delay also indicates that, despite some of the rather distant deadlines set in this amendment, it is not an easy task to meet this dual requirement.
- Based on their regularly published national ODS-related data and actions, the vast majority of Parties have contributed to curbing ozone layer depletion by complying with their commitments. Nonetheless, the implementation of the obligations of several countries (including some Central and Eastern European countries) has been significantly delayed; in view of this, a dedicated expert body was set up to monitor this issue and assist in resolving these problems.[580]
- International regulations also covered trade in the substances concerned, such as prohibiting trade in them with countries that were not Parties to the *Montreal Protocol*, and with few exceptions,

[579] "As was suggested by the original Molina and Rowland (1974) study on CFCs in the stratosphere, large concentrations of ODS in the atmosphere would have virtually destroyed the majority of the ozone layer by 2065 (global annual average losses >60%)." (p. 2124) "Total ozone falls from about 315 DU in 1974 to about 110 DU in 2065 in the World Avoided simulation." (p. 2117)

[580] The non-compliance procedure handled by the Implementation Committee: British environmental lawyer Patrick J. Széll played a major role in the legal foundation of this mechanism. He later also helped in the implementation of the climate change convention in the same area.

also between the Parties. As a consequence, this illegal trade increased, hindering the transition to less or no longer ozone-depleting substances and processes and putting those who comply with the regulations at a competitive disadvantage. In the 1990s, illegal shipments of freons, mainly to the USA and Western European countries, were estimated to be in the order of tens of thousands of tons [UNEP/DTIE, 2001]. Recurrently, decisions were adopted by the Parties to restrain this trade (see below).

- Global production of freons (CFCs) has decreased since the late 1980s: the previous volume of more than one million tons/year had declined by half by the early 1990s and then to a fifth a few years later. However, the pace of phasing out of both the 'hard' and 'soft' freons (HCFCs) was slower than expected. Because of this, the abundance of ozone-depleting chlorine and bromine in the troposphere decreased more slowly than was formerly assumed[581] [GORMP, 2010][582] Nevertheless, as the global emissions of the controlled substances systematically lessened, more recent assessments have already shown clear signs of a decrease in the total amount of chlorine and bromine entering the stratosphere [GORMP, 2018][583].

3.4.2. The need for systematic efforts to "heal" the ozone layer

Failure to comply with international commitments and the re-release of already phased-out ozone-depleting substances into the atmosphere and/or their illegal trade raised concerns about the *legal and environmental effectiveness* of the international regulations aimed at saving the ozone layer and efforts to comply with them.

- Unexpectedly, increasing atmospheric emissions of Freon-11 were detected, followed by an investigation into their causes and/or sources: "CFC-11 still contributes one-quarter of all chlorine reaching the stratosphere and a timely recovery of the stratospheric ozone layer depends on the sustained decline in CFC-11 concentrations. Here we show that the rate of decline in atmospheric CFC-11 concentrations observed at remote measurement sites was constant from 2002 to 2012 and then slowed by about 50% after 2012. […] The increase in CFC-11 emission appears unrelated to past production, suggesting unreported new production, which is inconsistent with the Montreal Protocol agreement to phase out global CFC production by 2010". [Montzka, 2018: p. 413] It was hoped that this hazardous situation would end and not recur in the future: "The unexpected emissions of CFC 11 declined after 2018. The continued elimination of this emission and the production that has caused it will prevent a substantial impact on ozone and climate.

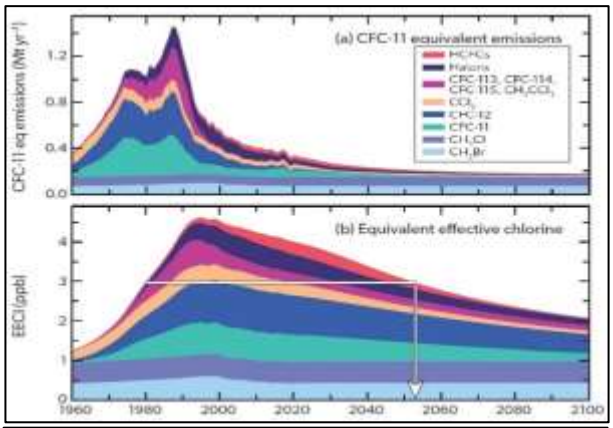

Figure 4A (a) CFC-11 equivalent emissions and (b) Equivalent effective chlorine. Observed data, 1960-2020 and scenarios by 2100 [WMO, 2022].

[581] "[T]he rate of decline in total tropospheric chlorine by 2008 was only two-thirds as fast as was expected. […] The discrepancy in CFC decreases is most likely because of emissions from 'banks' in existing applications such as refrigerators, air conditioners, and foams. The rapid HCFC increases are coincident with increased production in developing countries, particularly in East Asia. […] Total chlorine has continued to decline from its 1990s peak values in both the troposphere and the stratosphere. Total tropospheric bromine is decreasing from its peak values, which occurred comparatively recently, while stratospheric bromine is no longer increasing." (p. ES.1-3)

[582] One of the co-authors of this report was the Hungarian professor Imre Jánosi (ELTE).

[583] "Total chlorine entering the stratosphere from well-mixed ODSs declined by 405 ppt (12%) between the 1993 peak (3582 ppt) and 2016 (3177 ppt). […] About 80% of the chlorine entering the stratosphere annually is of anthropogenic origin. Total bromine entering the stratosphere from well-mixed ODSs declined by 2.4 ppt (15%) between the 1998 peak (16.9 ppt) and 2016 (14.5 ppt)." (p. ES.20)

Cumulative unexpected emissions over 2012–2019 have been estimated at 120–440 Gg. Since then, these annual emissions have diminished substantially from their peak amount" [WMO, 2022: pp. 40-41].[584] Furthermore, new measures had to be taken to prevent the illegal production and trade of substances controlled under the *Montreal Protocol* [UNEP, 2020; UNEP, 2022][585].

- If new CFC emissions had not been curbed in the then foreseeable future, this would have extended the 'healing' of the ozone layer by up to at least a decade [Dhomse et al., 2019; Solomon et al., 2020[586]]. The same applies to the aforementioned efforts to crack down on illegal trade.
- In more recent international reports, it was assumed that such excess emissions would no longer occur and that all Parties would fully comply with their ozone protection obligations. In this case, the return of stratospheric ozone to 1980 levels globally would be delayed by only one year, and a maximum of three years concerning the Antarctic 'ozone hole' [WMO, 2021].[587]

Solving the 'ozone layer problem' may be more difficult than previously expected. Regeneration is a slow process and may take longer: on the one hand, due to the delay in transitioning to 'ozone-friendly' substances, and on the other, due to the indirect effects of climate change.

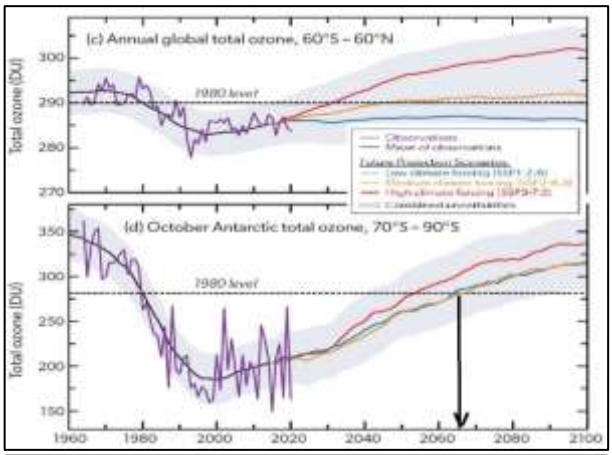

Figure 4B (c) Annual global total ozone, 60°S – 60°N, (d) October Antarctic total ozone, 70°S – 90°S. Observed data, 1960-2020 and scenarios by 2100 [WMO, 2022].

- Primarily thanks to the gradually expanded and tightened international regulations on the production and consumption of all ozone-depleting substances and their compliance by the vast majority of Parties, the total emission of these substances (measured in CFC-11 equivalent) has slowly but clearly declined since the late 2010s: Figure 4A (a). In parallel to this, the atmospheric concentration of 'ozone-destructuring' elements (halogens) has continued its decrease (measured in chlorine equivalents): Figure 4A (b). All of this could finally lead to a slightly increasing trend in atmospheric total ozone (Figure 4B (c) and 4B (d)). These improving tendencies were more pronounced than in data series from a few years ago [GORMP, 2018],[588] including those related to the ozone layer above the Antarctic: "New results since the 2018 Assessment support the findings reported at that time that the

[584] Recently, similar problems were also raised regarding other substances: "Unexplained emissions have been identified for other ODSs (CFCs-13, 112a, 113a, 114a, 115, and CCl4), as well as HFC-23. Some of these unexplained emissions are likely occurring as leaks of feedstocks or by-products, and the remainder is not understood." [UNEP/OEWG, 2024: p. 13]

[585] Decision XXXI/3: Unexpected emissions of CFC-11 and institutional processes to be enhanced to strengthen the effective implementation and enforcement of the Montreal Protocol (2019) [UNEP, 2020]. Decision XXXIV/8: Strengthening Montreal Protocol institutions, including for combatting illegal trade [UNEP, 2022].

[586] "[S]o far, the added CFC-11 has not been enough to significantly delay the closing of the ozone hole, but continuing additions beyond 2030 would impede successful healing of the ozone layer by a decade or more". (p. 2)

[587] "The anticipated recovery from stratospheric ozone depletion will not be substantially delayed by these enhanced CFC-11 emissions, because they were significantly elevated only for a brief period (2014–2019). […] Ozone recovery, measured as a return to 1980 levels, is delayed by only 0.4–1.3 years globally and by 0.5–3.1 years for the Antarctic ozone hole." (p. ES.1.4.)

[588] "For the first time, there are emerging indications that the Antarctic ozone hole has diminished in size and depth since the year 2000, with the clearest changes occurring during early spring. Although accounting for natural variability is challenging, the weight of evidence suggests that the decline in ODSs made a substantial contribution to the observed trends." (p. ES.23) "There is some evidence for a decrease in global (60°S–60°N) lower stratospheric ozone from 2000 to 2016, but it is not statistically significant in most analyses." (p. ES.26)

Antarctic ozone hole has diminished in size and depth since the year 2000." [WMO, 2022: p. 221]

- Concerning the longer-term scenarios (Figure 4B), "Actions taken under the Montreal Protocol continue to contribute to ozone recovery. Recovery of ozone in the upper stratosphere is progressing. Total column ozone (TCO) in the Antarctic continues to recover […]. Outside of the Antarctic region (from 90°N to 60°S), the limited evidence of TCO recovery since 1996 has low confidence. TCO is expected to return to 1980 values around 2066 in the Antarctic" [WMO, 2022: p. 3]. The same progress and future assessments were echoed in the more recent UNEP reports [UNEP/OEWG, 2023; UNEP/ORM, 2024].

But attention must not wane: the scientific community should continue to monitor the state and changes of an environmental system or component even after the identification of hazardous anthropogenic impacts on it and when the implementation of adequate measures is already underway since the same or similar hazard(s) may re-emerge under the influence of other natural or human-induced factors. Regarding atmospheric ozone, the former may involve phenomena of highly variable intensities, such as the circumpolar vortex that develops recurrently over the Antarctic, volcanic eruptions, and smoke vortexes caused by extreme wildfires [WMO, 2023: p. 70; Solomon et al., 2023; Kessenich et al., 2023; Cheng et al., 2024[589]].

- Numerous chemical substances are released into the atmosphere that have relatively short 'lifetimes', but a fraction of them still reach the stratosphere and affect the ozone layer. "The Montreal Protocol does not control the production and consumption of very short-lived chlorine source gases, although the atmospheric abundances of some (notably dichloromethane, CH_2Cl_2) have increased substantially in recent years." [WMO, 2023: p. 18][590] Attention has also been drawn to this long-neglected issue at a recent expert meeting and to the need to eliminate these emissions [UNEP/ORM, 2024: p. 2].
- It was also revealed that rapidly developing space activities and new experiments with supersonic flights may again pose a threat to the atmospheric ozone formation process. The future extent of such high-altitude operations can only be estimated with great uncertainty but should not be ignored. UNEP's ozone research experts emphasized the importance of intensifying the observations and research about these activities and their potential consequences [UNEP/ORM, 2024].[591] Another potential risk posed by satellites is also worth considering, namely that during their reentry into the atmosphere, ozone-depleting aluminum particles are released [Ferreira et al., 2024].[592]

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[589] "[N]ew findings highlight that natural events, exacerbated by climate change, pose additional risks to this fragile atmospheric layer. With the increasing frequency and intensity of wildfires driven by global warming, the formation of SCVs and their impact on the stratosphere could become more common, posing a threat to the ozone layer." (SCV: smoke-charged vortex).

[590] "Other chlorine- and bromine-containing gases are released to the atmosphere from human activities. […] Most of these gases are very short-lived and only a small fraction of their emissions reaches the stratosphere. The contribution of very short-lived chlorinated gases from natural sources and human activities to total stratospheric chlorine was 63% larger in 2020 than in 1993, and now contributes about 4% (130 ppt) of the total chlorine entering the stratosphere …" (p. 18)

[591] "Stratospheric aerosol and ozone abundances are also potentially influenced by other human activities that are drawing increased attention. New proposals exist for a supersonic civil aviation fleet that would emit nitrogen oxides and other gases in the stratosphere. Present day rocket launches that bring satellites to orbit and the return of space hardware to the lower atmosphere both emit gases and aerosols in the stratosphere. Future projections of space activity show substantial growth in space activity and associated emissions." (p. 6)

[592] "[T]he population of reentering satellites in 2022 caused a 29.5% increase of aluminum in the atmosphere above the natural level, resulting in around 17 metric tons of aluminum oxides injected into the mesosphere. The byproducts generated by the reentry of satellites in a future scenario where mega-constellations come to fruition can reach over 360 metric tons per year. As aluminum oxide nanoparticles may remain in the atmosphere for decades, they can cause significant ozone depletion."

- While ozone-depleting substances and their substitutes have a significant greenhouse effect – which has been taken into account in connection with the climate change convention since the early 1990s and under the international agreement on ozone layer preservation from 2016 onwards – other greenhouse gases and climate change itself considerably influence atmospheric ozone formation. This matter was already raised two decades ago [IPCC-TEAP, 2005],[593] but the need for a thorough investigation of this 'feedback' has recently been re-emphasized in the context of a growing body of scientific research and findings on the current and expected future state of the climate system [Chipperfield & Bekki, 2024].[594]

3.5. CONCLUSIONS AND LESSONS LEARNED

Recognition of the threat to the ozone layer
and the international cooperation to protect it

> "The stratospheric ozone depletion issue […] might have become very serious if its discovery had not aroused concern amongst people in general and if early action had not been taken. Fortunately, we shall never know to what extent a very serious situation might otherwise have evolved."
>
> *Bert Bolin, 2007*[595]

The depletion of the ozone layer in the upper atmosphere became one of the most instructive indirect outcomes of the multifaceted globalization process – an unintentional, unforeseen, particularly dangerous, and extensive intervention in the natural environment that was fortunately recognized in time; thus, its treatment could begin. By experimenting with and creating (synthesizing) new chemical substances, it became possible to eliminate and replace several previously introduced but less suitable (and even harmful to health) substances and technologies – e.g., for refrigeration or other purposes. Much later, it became clear that these innovations had even more perilous 'side effects' on a global scale. Numerous historical examples can be cited of the insufficient prior impact assessments of new technical solutions (e.g., production processes), including especially their potential adverse implications. However, at least in the environmental field, the 'ozone layer problem' became the first particularly critical affair of global significance.

The depletion of the ozone layer was caused by an inadvertent human intervention, as the release of such chemicals into the atmosphere that previously did not exist in nature led to the intensive destruction of ozone molecules in the stratosphere, thereby disrupting the equilibrium established there by ozone formation and decomposition, driven by natural forces. These former substances were produced in increasing quantities from the 1930s onwards, and their production and consumption grew exponentially from the middle of the last century. The indication of potentially serious

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[593] "Future temperature changes related to GHG emissions are expected to enhance stratospheric ozone depletion in some parts of the stratosphere and decrease it in others. Increases in CO_2 concentration are expected to cool the stratosphere, which is known to reduce the rates of gas-phase ozone destruction in much of the stratosphere and thereby increase ozone concentrations at altitudes above about 25 km. In contrast, lower temperatures could decrease ozone concentrations at lower altitudes." (p. 24)

[594] "Understanding and forecasting the effects of climate change on stratospheric ozone have been a major outstanding challenge for several decades now and will remain one for years to come. While our knowledge of relevant atmospheric processes will improve, there will remain the issue of uncertainty in GHG scenarios which are based on societal decisions." (p. 2789)

[595] Bert Bolin addressed the ozone layer problem in a comprehensive analysis of the development of international cooperation on climate change, the 'handling' of which so far can be considered a good model (precedent) to follow for other global, human-induced environmental hazards. [Bolin, 2007: p. 158]

health effects caused by increasing ultraviolet radiation played a key role in overcoming doubts about the changing state of the ozone layer and its causes and in determining the necessary policy responses.

- Although assumptions and theories were put forward that pointed to human activities endangering the ozone layer, proving its depletion and clarifying the effect of some halogenated hydrocarbons in that process (primarily of compounds such as Freon-11 and Freon-12) has not been an easy task. The longstanding despair and skepticism about the existence of a declining trend in stratospheric ozone abundance and ambiguity about its anthropogenic causes have also been driven by economic interests, the aforementioned technological 'inertia' ('lock-in effect'), and related consumption habits. Actually, such broadly interpreted skepticism may be a particularly positive catalyst in scientific research,[596] but obviously, the factors described above were mainly behind the fact that even those precautionary ozone-layer-protection measures that could have been implemented without any particular difficulty were not approved at the international level until 1985 [Faries, 1990[597]; Faragó, 2018: p. 5].
- Research into the possible health-damaging effects of UV-B radiation – which would be exacerbated by the then-hypothesized 'thinning' of the ozone layer – and their widespread communication resulted in growing public concerns from the late 1970s onwards. As a result, in several countries, demand sharply declined for products containing substances that were then suspected to be potential ozone depleters (first of all, aerosol spray cans with freon propellants).
- In this context, the increased likelihood of skin cancer and eye damage was the focus of environmental health studies [Green & Heidinger, 1978[598]; WHO, 1979; WHO, 1994[599]]. The 'ozone layer problem' has also highlighted how, in all other cases, the awareness of probable or at least partially proven direct harm to human health and quality of life can have significant impacts, catalyzing actions intended to counter the presumed causes of the respective hazardous environmental processes.

The development and institutionalization of international and interdisciplinary scientific relations have greatly contributed to the advancement of ozone-layer-protection decision-making. This cooperation has facilitated the improvement and dissemination of scientific knowledge about this hazardous process and the acceptance of the need for appropriate international response policies.

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[596] This is a reference to a thought by Denis Diderot: "Le scepticisme est donc le premier pas vers la vérité." / "Skepticism is the first step towards truth" (Pensées Philosophiques, 1746, p. 140: XXXI). (It was also quoted by the author of this book in the broader context of the discovery of various environmental hazards [Faragó, 2018].)

[597] (In 1980:) "Other nations, including members of the European Economic Community (EEC) pointed to scientific data which suggested ozone layer depletion was not nearly as drastic as some anticipated […] and contended that the reduction of CFC use would do little to ameliorate the predicament. Scientific uncertainty in the area was utilized to its full extent by each country in promoting national interests, and consequently negotiations towards a multi-lateral agreement were sluggish." (p. 828)

[598] "Here we summarize the nature of the various approaches used in work relating ultraviolet (UV) doses to non-melanoma skin cancer (SC). Under pressure generated by public policy questions related to the possible modification of the ozone layer by supersonic transports or freon release, the literature on this topic has developed quite rapidly." (p. 283)

[599] Environment (1.6.): "Increased levels of UV due to ozone layer depletion may have serious consequences for living organisms. A 10% reduction in ozone could lead to as much as a 15-20% increase in UV exposure depending on the biological process being considered." Guidelines on Exposure Limits and Protective Measures (1.7.): "With increasing levels of solar UV resulting from depletion of the ozone layer, and the continuing rise in the level of melanoma worldwide, people should become more aware of their UV exposure and take appropriate precautions." Eye (15.6.3.): "there is evidence of the depletion of the ozone layer and the reported consequent increase in ambient UV which will impact on many eye diseases."

- First of all, it was recognized that atmospheric ozone observations need to be extended to different geographical locations, and thus, it was advisable to establish international cooperation in this regard. The organization of such a network was initiated and begun by Gordon Dobson, and a global system and data center for ozone observations was established in 1957. Over time, this helped with understanding that ozone layer depletion is ongoing and its consequences affect everyone, everywhere.
- Research collaboration also became of paramount prominence, especially since the possibility of an anthropogenic threat to the ozone layer had arisen, or – as Robert T. Watson, then chairman of one of the expert bodies on this matter, put it – humanity had embarked on a "giant experiment" by disrupting the natural cycle of various atmospheric trace gases, including chlorine, on a global scale [UNEP/CCOL, 1984].[600]
- Highlighting the key scientific findings and offering a clear summary of science-based recommendations could help decision-makers better understand the severity of the issue and determine the necessary measures based on the level of scientific certainty achieved regarding the cause-and-effect relationships associated with this hazardous process. This practice has been followed by research teams since the early 1980s. At first, they limited themselves to emphasizing the main results of the analysis of observations and the essence of the model calculations, but after a while, they also communicated the recommended courses of action.[601]

The acceptance of the principle of the precautionary approach and the differentiated responsibilities for the (then still only presumed) threat to the ozone layer was necessary for the universal adoption of commitments and measures to preserve the ozone layer.

- Research into the ozone layer problematic would not have ended with the discovery of the 'ozone hole', but it has become much more intensive, including the most accurate assessments of the ozone-depleting effects of various substances. Due to the still limited level of scientific evidence at the time, the *Montreal Protocol* (1987) relied primarily on the precautionary principle.[602] Nevertheless, the negotiating parties were able to agree on the first time-bound targets for reducing the production and consumption of several ozone-depleting substances that were already being used in large quantities worldwide.
- For a long time, the manufacturing of those freons and halons was primarily carried out in a few developed countries, and it was also there that the products and some technological procedures that effectively utilized these substances were first spread on a wider scale. Consequently, for decades, those countries had much greater responsibility than the developing countries for the overall atmospheric emissions of ozone-depleting substances and, thus, for the (unintentional) damage to the ozone layer. Although the ozone layer protection agreements did not explicitly cite the 'common but differentiated responsibilities' for this hazard, for this very reason, as early as 1987, the 'special situation' of developing countries in this regard was acknowledged.[603] Moreover, in 1990, a decision was made on a financial fund to support these countries in fulfilling their obligations related to the relevant ozone layer protection measures. The Central and Eastern European countries with 'economies in transition' that

[600] "(m) In conclusion, it should be noted that the equivalent of one giant experiment is being performed on the atmosphere. Mankind is perturbing the carbon, nitrogen, hydrogen and chlorine cycles on a global scale and in an unprecedented manner. The consequences of this for the future cannot be known with any certainty."

[601] The concise summaries of these reports by CCOL, IOTP, and GORMP were published under titles such as 'Executive summary', 'Scientific summary', 'Science summary', and 'Key findings'. From 1991 onwards, GORMP reports highlighted not only the essence of scientific results but also conclusions relevant to decision-making under different headlines: 'Implications for policy formulations' and 'Information for policymakers and options for policy formulation'.

[602] "Determined to protect the ozone layer by taking precautionary measures to control equitably total global emissions of substances that deplete it, with the ultimate objective of their elimination on the basis of developments in scientific knowledge". [VCPO/MP, 1987]

[603] "Article 5. Special situation of developing countries" [VCPO/MP, 1987].

were then in difficult economic conditions also appealed for such assistance, which was granted from another international financial fund. Taking these different circumstances into account, providing subsidies to the 'eligible' countries above and restricting trade with non-Parties to these agreements also encouraged all countries to participate in the implementation of the commonly adopted regulations on the ozone layer.

The execution of the measures adopted to halt ozone layer depletion was accompanied by the amplification of another global environmental problem. The history of imperiling and saving the ozone layer could not, therefore, end with the transition to the 'ozone-friendly' compounds and industrial processes, but such interventions were needed that would not lead to the aggravation of another hazardous process.

- In parallel with the tightening of procedures for the preservation of the ozone layer, international legal instruments on climate change were created: following the 1992 *UN Framework Convention on Climate Change*, the *Kyoto Protocol* (1997), then its *Doha Amendment* (2012) and most recently, the 2015 *Paris Agreement*. For almost three decades, the case of chemical materials that have been 'at the crossroads' of these two environmental policy areas remained unresolved. Some of these substances were very appropriate in terms of ozone layer protection (substituting the previous ozone-depleting ones), but were quite harmful from a climate protection perspective.
- In addition to this serious 'ozone-vs-climate'-policy-related contradictory situation, it is worth mentioning the positive influence of the foregoing ozone policy agreements (1985-1987) on the climate policy negotiations that began in 1991, at least in terms of the (partial) adoption of some procedural and substantive elements ('samples') of the former, which proved to be equally useful for the climate policy solutions and compromise-settings.[604]
- The most controversial situation emerged in 1992 when one of the decisions required the transition to 'ozone-friendly' substances (HFCs) to begin in order to protect the ozone layer, while just a few months earlier, reducing the emissions of all such substances – extremely potent greenhouse gases – was on the agenda of the intergovernmental meeting about the climate change hazard.
- When it seemed inevitable in the field of ozone layer protection that the significant greenhouse effect ('global warming potential') of the above-mentioned compounds would be taken into account, the representatives of the Parties to the *Montreal Protocol* acknowledged: "Noting the need to implement multilateral environmental agreements in a coherent way for the benefit of the global environment" (Decision X/16, 1998).
- The interactions between these two dangerous environmental processes and the procedures introduced to address them show that it is not sufficient to (only) examine the various anthropogenic environmental and related socioeconomic problems in isolation, but rather their interlinkages and the occasional cross-effects of the (planned) interventions must also be studied. Therefore, a comprehensive and coherent approach is necessary when developing such agreements and programs, and not only in the course of their implementation when already serious 'side effects' are detected. In other words, failure to identify (i) interactions between hazardous processes to be addressed independently and (ii) any adverse cross-effects of the measures enacted to address such problems may result in environmental policy decisions and interventions that are much less effective or may even inadvertently lead to other very grave harms.

[604] The author of this book has presented and evaluated these precedent-setting solutions in detail [Faragó, 2016], as well as the quota-trading mechanism introduced in connection with both environmental agreements [Faragó, 2011]. Those partially similar 'building blocks' included, inter alia, the differentiation of obligations, some 'flexibility instruments', institutional arrangements for the science-policy interface, etc.

- Environmental policy institutions, programs, and agreements specializing in particular environmental issues have been created in a parallel manner similar to the scientific networks, commissions, and expert bodies that study specific environmental processes. A 'classic' example of this is the establishment and operation of separate multilateral institutional and regulatory systems for the ozone layer and the climate change problematics. Consequently, inter- and multidisciplinary, inter- and cross-sectoral, and interinstitutional cooperation is also essential for creating effective policy responses intended to tackle interrelated environmental issues, such as those which (after some time) developed with the collaboration of the governing and expert bodies of the ozone and climate-related international agreements.
- The fate of 'semi-orphan' substances (HFCs and PFCs) was resolved at the end of 2016 when the Parties to the *Montreal Protocol* showed their willingness to take care of these 'ozone-friendly' but not 'climate-friendly' chemicals in a regulatory sense. By doing so, measures were finally advocated to curb ozone layer depletion that would not lead to the strengthening of another global environmental threat addressed by another international cooperation mechanism.

The sufficiency and effectiveness of the international regulations developed to protect the ozone layer depend on their content ('ambition level') and actual implementation (like any other environmental regulatory instruments), and these can ultimately be measured by whether they eventually result in, on the one hand, the elimination of the ozone layer depletion hazard caused by 'irresponsible' human activities and on the other, the recovery of that layer.

- International environmental (and other) policy and legal instruments – including those aimed at ozone layer preservation – may be deemed sufficient insofar as (i) the possibility of meeting their (ultimate) objectives is not weakened by numerous compromises (made for whatever reasons) concerning the adopted policies and measures, (ii) they are accepted by all parties, (iii) all the obligations are thoroughly complied with, and (iv) neither illegal nor novel activities take place that would cause the recurrence of the same problem(s).
- It is not self-evident that large-scale (transboundary or global) hazardous environmental matters may be solved 'simply' by concluding an international agreement; therefore, the latter's implementation must also be closely followed up [Hegglin, 2018].[605] In addition to expecting and checking compliance with already adopted commitments, it is also important to regularly examine their sufficiency and, if it seems necessary, to revise (enhance and/or supplement) them. Typically, this led to the repeated 'tightening' and complementing of the provisions of the *Montreal Protocol*, e.g., by gradually extending the list of controlled substances and strengthening the obligations for preventing the illegal production, environmental release, or trade of ozone-depleting substances.

* * *

The most important overall conclusions and lessons learned:

- thanks to international scientific and policy cooperation and an appropriate science-policy interface, the policies and measures adopted and implemented so far, including especially those that help phase out ozone-depleting substances and accelerate their substitution, have proved to be effective in 'saving' the ozone layer and achieving the beginning of its slow regeneration;
- although the elimination of the production and consumption of the majority of ozone-depleting chemical compounds can be completed within the foreseeable future, it will still be a long time before the ozone layer returns to its safe, former state;

[605] "[E]nvironmental regulations cannot be taken for granted and have to be safeguarded, and that monitoring is required to ensure compliance." (p. 318)

- more concretely, the use and emissions of ozone-damaging substances led to an acceleration in the threat to the ozone layer for about four decades (from the mid-20th century onwards), and it is expected that at least another four decades will have to pass until the implementation of the respective international agreements permit the ozone shield to effectively undertake its (literally) vital function again.

4. OVERHEATING OUR COMMON GREENHOUSE

THE ACCELERATING CLIMATE CHANGE PROCESS, EXPLORATION OF ITS CAUSAL LINKS AND THE INTERNATIONAL POLICY COOPERATION TO HANDLE THIS HAZARD

An extraordinary hot day in Budapest (photo taken by the author on Aug. 3, 2017)

"I have calculated the mean alteration of temperature that would follow if the quantity of carbonic acid varied from its present mean value […] the temperature in the arctic regions would rise about 8° to 9° C, if the carbonic acid increased to 2.5 or 3 times its present value."

Svante Arrhenius, 1896[606]

"But suppose the climate changes by a whole degree in a century, which is a huge change in any case, would we be able to detect this change today?"

Róna Zsigmond, 1909[607]

"By fuel combustion man has added about 150,000 million tons of carbon dioxide to the air during the past half century. […] approximately three quarters of this has remained in the atmosphere. […] the increase in mean temperature, due to the artificial production of carbon dioxide, is estimated to be at the rate of 0.003°C per year at the present time."

Guy Steward Callendar, 1938[608]

The identification of human impacts on the concentration and environmental cycle of atmospheric trace gases that play a prominent role in the state of the Earth's climate and the assessment of the possible consequences of human interference with this global environmental system began about two centuries ago. Compared to many other expansive interactions among the natural environment and societies, uncovering causal relationships associated with this matter of concern has proven more difficult. In this chapter, after presenting the key turning points in scientific research on this theme, the development of international scientific and policy cooperation on the variability and changes in the state of the global climate system will be reviewed and evaluated, including the latest progress. After this, the most important conclusions and lessons will be summarized.

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[606] Arrhenius wished to contribute to a better understanding of the climate changes that have occurred throughout Earth's history, focusing on the changing concentration of atmospheric 'carbonic acid' (i.e., carbon dioxide). He referred to A.G. Högbom, who analyzed what could happen on a global scale as a result of coal use: "The world's present production of coal reaches in round numbers 500 millions of tons per annum […]. Transformed into carbonic acid, this quantity would correspond to about a thousandth part of the carbonic acid in the atmosphere".

[607] Róna pointed out that, at the time, there was no "completely homogeneous, sufficiently long and accurate observation series […] to find out whether the climate is changing, albeit slowly, but still continuously, in one direction." [Róna, 1909: p. 526]

[608] [Callendar, 1938: p. 223]

4.1. GLOBAL CLIMATE CHANGE:
ASSUMPTIONS, DOUBTS, AND CERTAINTY

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nature-driven shorter and longer-term changes have always occurred

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and the extent of their (f)actual fulfillment

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4.5. CONCLUSIONS AND LESSONS LEARNED

4.1. GLOBAL CLIMATE CHANGE: ASSUMPTIONS, DOUBTS, AND CERTAINTY

4.1.1. The climate system: nature-driven shorter and longer-term changes have always occurred

The state of the climate system has changed many times throughout human history, although not as widely as during the few billion years of Earth's history, including the very long ice ages. The periods of glaciation and warmer stages in between (the interglacial periods) were driven by more or less well-identified natural processes related to geophysical factors and cycles in the Earth's circulation. In comparison, much more moderate climatic fluctuations over periods of several centuries, decades, or a few years can be attributed to other causes or are the consequences of internal perturbations of this huge environmental system. Climate variability was already evident to societies in early historical times, as it directly affected people's lives, but the detailed description and in-depth scientific investigation of the spatial and temporal characteristics and effects of these phenomena only happened later. From the second half of the 19th century, the question arose more frequently whether significant changes similar to those in the distant past should be expected. Hungarian researcher Mihály Soós, recalling the changes that took place in geological eras, argued and asked the following legitimate question: "Such violent transformations undoubtedly changed the general character of climatic conditions, but in the absence of direct data, the geographical distribution of the remains of prehistoric creatures locked in the depths of the earth provides evidence. Is there such a change in a general sense at present? Only a more fortunate posterity than ours can decide this." [Soós, 1870] Almost four decades later, meteorologist Zsigmond Róna expressed a similar opinion: "We can only seriously find meteorological evidence for unidirectional climate change if we have homogeneous records spanning one or two hundred years." [Róna, 1909]

Even in ancient times, attention was paid to the sometimes extreme variability of environmental conditions and their effects on basic living conditions in several regions and countries.

- Perhaps the best-known and most illustrative ancient example of tracking climatic fluctuations and their effects concerns the variation in the amount of rainfall during the summer monsoon period in the Nile basin and its social, economic, and political implications for Egypt. In the lower reaches of the Nile, the annual flood level, the resulting water volume, and sediment were of crucial importance for agriculture in that region and, consequently, for the food security and prosperity of the Egyptian population.
- From ancient records, the hieroglyphics on the famous 'Palermo Stone', or papyrus scroll remains, it has become clear that the flood level was measured and recorded [Bell, 1970; Hsu, 2010]. Unfavorable periods of rainfall and water scarcity had serious consequences: "The workers' strikes and food riots (at least six major incidents are recorded between 1153 and 1105 B.C.) are inescapably linked to the wild inflation of food prices coincident with the major, negative readjustment of Nile hydrology […] The economic history of Egypt was closely dependent on the Nile and its behavior. Egypt was, after all, the gift of the river, and the river was for the cosmic order to control." [Butzer, 1984: p. 10].
- Reviewing the dependence of the lives of ancient societies on the natural environment and, as a part of it, the state of the atmospheric environment (primarily, the variability in temperature and precipitation), academician Ernő Mészáros put it this way: "However, at the dawn of history, man was incapable of providing scientific explanations. So, they populated nature with supernatural beings who 'control' various phenomena […]. The existence of gods of the air was first

questioned by Greek thinkers. They tried to explain natural phenomena in a rational way" [Mészáros, 2008].

- Nothing seems to have changed over time regarding this environmental dependence. In 2011, crop failures due to unfavorable natural conditions in Egypt and its wider region, as well as in the main grain-exporting countries, contributed to the series of events known as the 'Arab Spring' sometimes simply interpreted as hunger revolts [Johnstone & Mazo, 2013].

The detection of longer-term, large-scale climate anomalies and their effects was facilitated by the expansion of climate observational networks and the development of descriptive climatology (climatography, then climatology).

- Based on the archived observational data it was possible to identify longer-term warmer and colder periods, such as the ancient Roman Climate Optimum, the Medieval Warm Period, the Little Ice Age that spanned several centuries, and the shorter, particularly dry and warmer span that has severely affected the Sahel region since the late 1960s.
- Extreme and prolonged hotter, dryer, or colder periods have occurred everywhere, often with severe socioeconomic implications for local societies. Antal Réthly systematically documented such events from old Hungarian records, which could be reconstructed until 1900 [Réthly, 1962, 1970, 1998]. Relying on data from these collections, Lajos Rácz investigated the effects of the Little Ice Age in this region in great detail [Rácz, 2021].

Cyclical changes in global climate. The more or less regularly alternating long-term changes in the state of the climate system and the natural factors that presumably cause ('govern') them have been studied thoroughly by scientists since the 19th century.

- The possibility of climate fluctuations triggered by sunspot cycles was raised by William Hershel, while others confirmed or questioned the climate-regulating role of these cycles [Hershel, 1801; Köppen, 1873; Huntington, 1914; Abbot, 1967; Roy & Haigh, 2012].[609] According to the Intergovernmental Panel on Climate Change, this factor has no or only a minor impact on a global scale, while "there is medium confidence that the 11-year cycle of solar variability influences decadal climate fluctuations in some regions" [IPCC, 2013].
- The 'El Niño' phenomenon was first mentioned by this name in the late 19th century, referring to a warm ocean current in the upper layer of the Pacific Ocean near the coast of South America that recurs every few years [Carrillo, 1892; Pezet, 1896]. Jacob Bjerknes demonstrated the connection between these warmer oceanic episodes and the Southern Oscillation discovered by Gilbert Walker, an atmospheric flow process that also causes remote climatic effects [Walker, 1924; Bjerknes, 1969].
- By examining the variations in the Earth's orbit, Joseph Adhemar in 1842 and then James Croll in 1866 derived their connection with glacial epochs. Milutin Milankovitch much more systematically analyzed the effect of these periodic changes on the distribution of the solar radiation reaching the Earth's surface over the past several hundred thousand years and thus on the occurrence and duration of the glaciation periods [Milankovitch, 1920].[610] This theory was refined by György Bacsák with regard to interglacial periods [Bacsák, 1940; Major, 2006]. László Kordos presented some other paleoclimatological theories and related research on regional paleoclimatic changes [Kordos, 1979].

[609] After examining the possible relationship between the sunspot cycles and average annual temperatures in Hungary, Zsigmond Róna could not demonstrate a clear correlation [Róna, 1909; pp. 528-535]. A similarly cautious opinion about this matter was expressed much later by another prestigious researcher [Bacsó et al., 1953: p. 32].

[610] These changes in the movements of the Earth and their periods of cyclical variation in terms of thousands of years in the order mentioned above: precession (about 21), orbital eccentricity (about 100), and obliquity (about 41).

The radiation-transmitting properties of the atmosphere and its changes. Nineteenth-century scientists achieved substantial results in relation to this topic by applying physical and mathematical methods and relying on much more observational data than before.

- Joseph Fourier developed mathematical equations applicable to the heat transfer resulting from solar radiation reaching the Earth and the effect of the atmosphere on the spatial and temporal variations of surface temperature [Fourier, 1822]. He indirectly also referred to the 'greenhouse effect' of the atmosphere by mentioning the 'greenhouse' as an analogy.[611] Later, he addressed more thoroughly the relationship between atmospheric radiation transfer and Earth's surface temperature, but again only making a metaphorical reference to the greenhouse effect of the atmosphere [Fourier, 1827[612]; Haszpra, 2010].
- In 1856, Eunice Foote studied the warming effect of solar radiation. She determined that moist air warmed up more than dry air, and this happened even more when the Sun's rays passed through a sealed glass cylinder filled with carbonic acid (i.e., carbon dioxide) [Foote, 1856]. She also indicated quite clearly that if the carbon dioxide content in the atmosphere were to increase at some point in the future, it would be accompanied by a rise in temperature.[613] László Haszpra cited this important experiment and accurately interpreted its results to mean that it was *not* actually about recognizing the atmospheric greenhouse effect but "the absorption of near-infrared radiation from the Sun" [Haszpra, 2022: p. 61].
- From 1859 onward, John Tyndall used his own equipment (an absorption spectroscope) to investigate, among other things, the absorption of infrared radiation by atmospheric gases [Tyndall, 1862]. He demonstrated the key role of water vapor and carbon dioxide in this matter: "The differential action of the heat coming from the sun to the earth, and that radiated from the earth into space, is vastly augmented by the aqueous vapour of the atmosphere. […] Now if, as the above experiments indicate, the chief influence be exercised by the aqueous vapour, every variation of this constituent must produce a change of climate. Similar remarks would apply to the carbonic acid diffused through the air […]. The thirtieth of an atmosphere of [that] gas cuts off half the entire radiation …" [Tyndall, 1872: p. 39, p. 232].

Carbon dioxide in the atmosphere and the climate. A closer consideration of this relationship marked a new phase in climate change research.

- Svante Arrhenius, at the end of the 19th century, not only took into account Fourier's findings, Tyndall's atmospheric absorption measurements and derivations, and the results of other researchers (e.g., Samuel Langley) but was also interested in how the surface temperature would vary if the amount of 'carbonic acid' in the atmosphere changed, and how this would affect the water vapor concentration [Arrhenius, 1896].[614] He estimated how much cooling would result if the amount of carbon dioxide decreased (as it did during ice ages and glaciations) and that doubling the abundance of carbon dioxide would result in warming of 5-6°C. There is a reference in his article – with a quote taken from Arvid Högbom's earlier paper – that the latter change could be caused by excess carbon dioxide entering the atmosphere due to human activities [Högbom, 1894].

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[611] "[L]es théorèmes concernant l'échauffement de l'air dans les espaces clos […]. Il sera utile d'y recourir lorsqu'on voudra prévoir et régler la température avec quelque précision, comme dans les serres".

[612] "L'interposition de l'air modifie beaucoup les effets de la chaleur à la surface du globe […]. La chaleur du soleil, arrivant à l'état de lumière, possède la propriété de pénétrer les substances solides ou liquides diaphanes, et la perd presque entièrement lorsqu'elle s'est convertie, par sa communication aux corps terrestres, en chaleur rayonnante obscure. Cette distinction de la chaleur lumineuse et de la chaleur obscure explique l'élévation de température causée par les corps transparents." (p. 573)

[613] "The highest effect of the sun's rays I have found to be in carbonic acid gas. […] An atmosphere of that gas would give to our earth a high temperature" (p. 383)

[614] We refer to this in the quote at the very beginning of this chapter.

- Thomas Chamberlin confirmed the climate-regulating property of carbon dioxide – in interaction with water vapor – referring to Arrhenius and Högbom: "[A]n increase of carbon dioxide raises the temperature, it increases the quantity of water vapor and this by its thermal absorption further increases the temperature and calls forth more vapor and this action and reaction continue in diminishing force until an equilibrium is established." [Chamberlin, 1899: p. 552] Nils Ekholm pointed out even more clearly the greenhouse effect of atmospheric carbon dioxide, which is the same as that caused by "the glass of the green house" [Ekholm, 1901].[615] (An excellent overview of the development of this theory and the activities of the above-mentioned and other researchers, and their collaborations was published on the occasion of the centennial anniversary of Arrhenius's famous paper [Crawford, 1997].)
- In addition to the astronomic theories about Earth's orbital cycles and their climatic effects, Milutin Milankovitch, in a most comprehensive book, also discussed briefly the role of atmospheric water vapor and carbon dioxide in the formation of ice ages and cited the relevant calculations and theories of Tyndall, Arrhenius, Matchi, and Ekholm [Milankovitch, 1941].[616]

The 'water vapor and/or carbon dioxide' debate. Since the late 19th century, there has been lengthy speculation about if, and if so, how, changes in the amount of atmospheric carbon dioxide could influence long-wave radiation from the Earth and, thus, the atmospheric greenhouse effect.

- The arguments and counterarguments mainly revolved around whether the narrow absorption bands of carbon dioxide in the long-wave (infrared) radiation range are completely covered by the broader absorption bands of water vapor. According to Knut Ångström, Arrhenius misinterpreted the data from these bands, so his statements about the effects of changes in carbon dioxide levels were incorrect [Ångström, 1900].[617] This was not simply an expression of doubt but also a presentation of counter-evidence.
- In the next few decades, the skepticism of others about such relationships was also made clear: Robert Wood generally questioned the existence of the atmospheric greenhouse effect, William Humphreys believed that carbon dioxide had no significant influence on climate, and George Simpson argued that only water vapor in the atmosphere was involved in the absorption and emission of long-wave radiation [Wood, 1909[618]; Humphreys, 1913; Simpson, 1929[619]].
- Arrhenius responded to all the criticisms (1901), and three decades later, Edward Hulburt – taking into account in more detail than before the abundance of atmospheric gases varying with altitude, their absorption characteristics, and the effect of heat transfer from the surface – found that

[615] "[T]he carbonic acid in the atmosphere acts as the glass of the green house" (p. 21); "the present burning of pit-coal is so great […] it will undoubtedly cause a very obvious rise of the mean temperature of the Earth." (p. 60)

[616] "Schon Tyndall hat nachgewiesen […] Die Atmosphäre enthält von diesen Verbindungen, wie bereits gesagt, Wasserdampf und Kohlensäure, und diese Gase sind es, die den grösseren Teil der Sonnenstrahlung und fast die gesamte Ausstrahlung der Erdoberfläche absorbieren." (p. 448) Wie gross der Anteil jedes dieser beiden Gase an dieser Transmission ist, darüber gibt uns eine diesbezügliche Untersuchung Ekho1m's wenigstens annähernd Auskunft. Darnach soll die trockene Luft samt der Kohlensäure rund 25 Prozent, der Wasserdampf dagegen 60 Prozent absorbieren (p. 550) "Den Einfluss, den der Wasserdampf bzw. die Kohlensäure auf die Absorption der Erdausstrahlung ausüben, haben L. de Marchi bzw. Arrhenius zur Grundlage ihrer Eiszeitentheorien gemacht." (p. 493)

[617] "Die Schwierigkeiten vermehren sich noch bedeutend, wenn Absorptionsbänder von zwei verschiedenen Elementen, hier Wasserdampf und Kohlensäure, sich übereinander lagern und es also auf die Trennung der beiden ankommt. In diesem Falle ist aber eine Behandlung des Beobachtungsmateriales, wie es Hr. Arrhenius versucht hat, nicht erlaubt." (p. 731)

[618] "The solar rays penetrate the atmosphere, warm the ground which in turn warms the atmosphere by contact and by convection currents […]. It seems to me very doubtful if the atmosphere is warmed to any great extent by absorbing the radiation from the ground". (p. 320)

[619] "It is assumed that water vapour is the only constituent of the atmosphere which absorbs and emits long wave radiation." (p. 73)

atmospheric carbon dioxide is a significant factor in shaping the global average surface temperature, justifying the theory proposed by Tyndall [Hulburt, 1931].[620]

4.1.2. Human-induced climate change: possible or not? A protracted and heated scientific debate

For a long time, studies on the causes of major changes in the state of the global climate system were primarily intended to shed light on how ice ages, alternating glaciation and ice-free periods have developed throughout geological history. Much later, it emerged that the Earth's climate could also be influenced by human activity. However, clarifying this possibility proved to be a difficult task. It appeared especially incomprehensible why the average surface temperature rise during approximately the last three decades did not continue for some time, although the amount of carbon dioxide and some other greenhouse gases emitted due to human activity had increased rapidly since the mid-20th century. Moreover, during the Cold War period, the concerns about the global environmental 'dark side-effects' of military operations involving mass destruction (nuclear strikes) also increased. An assessment of such (hopefully never occurring) potential consequences was also waiting for researchers.

The exploration of the possibility of the unfolding of anthropogenic climate change was largely made possible, above all, by the availability of more accurate data on the state and composition of the atmosphere, as well as their changes.

- Thanks to the development and application of instruments that allow for much finer-resolution measurements, as well as measurements at high altitudes, more knowledge has become available since the 1930s, including about the radiation absorption of atmospheric gases and, in general, on the properties and processes of the Earth's atmospheric environment. Later, the evaluation and modeling capabilities based on huge amounts of data were further expanded using computers. The latter made it possible to analyze in more detail atmospheric radiation transfer, including the role of greenhouse gases in this, and to examine the 'operation' of the climate system no longer exclusively with theoretical models. Due to the advanced environmental observation instruments and networks, as well as increasing data transmission and management capacities, more information became available about other large-scale environmental impacts of human activities.
- About forty years after the publication of the landmark papers by Högbom, Arrhenius, and Chamberlin, Guy Callendar derived how much carbon dioxide had been released into the atmosphere from the combustion of fossil fuels in the previous few decades and how and to what extent this had caused the average surface temperature to rise [Callendar, 1938]. For his calculations, he used data that had become somewhat more accurate and complete by then and/or that could be better estimated regarding (i) the concentrations of water vapor and carbon dioxide at different altitudes in the atmosphere, (ii) the radiation absorption, transmission, and emission properties of these gases, and (iii) the average surface temperature. He assessed how large the latter's rise would be in the 20th and 21st centuries according to the interrelations he assumed or demonstrated between the various parameters.[621]

The test of theory is reality. Both supporters and opponents of Callendar's claims on climate scenarios spoke out.

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[620] "[T]he calculation indicates that the carbon dioxide theory of the ice ages, originally proposed by Tyndall, is a possible theory." (p. 1876)

[621] "[T]he combustion of fossil fuel […] is likely to prove beneficial to mankind in several ways […]. In any case the return of the deadly glaciers should be delayed indefinitely. As regards the reserves of fuel these would be sufficient to give at least ten times as much carbon dioxide as there is in the air at present." (p. 236)

- The strongest refutation was issued by the American Meteorological Society, which stated that carbon dioxide has no role in absorbing long-wave radiation because it is absorbed by water vapor [Brooks, 1951].[622]
- With calculations that used more accurate absorption data, Lewis Kaplan and then Gilbert Plass agreed with the correctness of the 'carbon dioxide theory', as did Roger Revelle and Hans Suess – taking into account the environmental cycle of carbon, but expressing a much more cautious stance on the effects of all this [Kaplan, 1952; Plass, 1956[623]; Revelle & Suess, 1957[624]].
- This dispute continued for some time, but from the end of the 1950s, based on even more precise measurements and calculations, new results were derived about the presumed effects of anthropogenic carbon dioxide emissions. However, the rising global temperature trend was interrupted in the 1940s and was followed by a somewhat cooler period lasting about three decades. Polemics arose again about the factors 'governing' the climate system and whether fundamental climate change was even conceivable in the 20th century.[625]

The 'atmosphere versus ocean' debate: where could the excess carbon dioxide emitted into the atmosphere go? There was a separate scientific discussion about the fate of the increasing anthropogenic carbon dioxide emissions, i.e., primarily about how much of this quantity the world's oceans could absorb and at what rate.

- Some estimated that the ocean has a large effect on regulating the amount of carbon dioxide in the atmosphere and expressed doubts about the accuracy of Callendar's calculations showing the relationship between the growing abundance of carbon dioxide in the atmosphere and the rise in surface temperature [Panofsky, 1956; Revelle & Suess, 1957[626]].
- Callendar maintained that his earlier estimates were correct [Callendar, 1958], and then Bert Bolin and Erik Eriksson theorized that the upper oceanic mixing layer quickly became saturated with absorbed carbon dioxide, so a large proportion of the carbon dioxide emitted by human activities remained in the atmosphere and accumulated [Bolin & Eriksson, 1958].[627] The transfer of carbon dioxide between the atmosphere and the biosphere was also estimated more exactly by them.

The 'aerosol contra carbon dioxide' debate: is a period of global cooling approaching? Following the aforementioned halt in the warming trend, the possibility of the impact of other factors and the beginning of global cooling also arose.

- George Kukla claimed that a new glaciation period had begun and "mean global temperatures may eventually drop about 1°C in the next hundred years." [Kukla, 1972]
- Rising carbon dioxide emissions would result in about 0.6°C of warming by 2000, while aerosol emissions from human activities would also increase. For this reason, according to George Benton, the resulting implications for the climate are difficult to assess, and moreover, "the effect of pollution by natural volcanic activity must be considered. Unlike most activities of man, violent

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[622] The CO_2 theory of climate change "was never widely accepted and was abandoned when it was found that all the long-wave radiation absorbed by CO_2 is also absorbed by water vapour." (p. 1016)

[623] "[I]t does seem significant that there are many facts about world-wide variations in the climate that can be explained in a simple, straight-forward manner only by the CO_2 theory." (p. 152)

[624] "In contemplating the probably large increase in CO_2 production by fossil fuel combustion in coming decades we conclude that a total increase of 20 to 40 % in atmospheric CO_2 can be anticipated. This should certainly be adequate to allow a determination of the effects, if any, of changes in atmospheric carbon dioxide on weather and climate throughout the earth." (p. 26)

[625] The macroclimate: "The […] approximate validity of the averages for the period 1901-1930 can therefore be accepted as fact and indicative for the 20th century." [Bacsó et al., 1953: p. 33]

[626] "[A]verage lifetime of a CO_2 molecule in the atmosphere before it is dissolved into the sea is of the order of 10 years […] most of the CO_2 released by artificial fuel combustion since the beginning of the industrial revolution must have been absorbed by the oceans". (p. 18)

[627] "[L]ess than 10 percent of the excess fossil CO_2 in the atmosphere should have been taken by the mixed layer […] the mixed layer acts as a bottleneck in the transport of CO_2 to the deep sea". (p. 133)

volcanic eruptions inject particulates directly into the stratosphere, where they are most effective in cooling the earth. The drop in the earth's temperature since 1940 has been paralleled by a substantial increase in natural volcanism." [Benton, 1970: p. 898] Mikhail Budyko examined the effect of aerosols from both sources, which had to be taken into account to explain the temperature decrease after 1940 [Budyko, 1969].[628]

'Eppur si': those who still claimed that warming would continue.[629] As observational data accumulated and their quality and 'resolution' improved, more and more researchers agreed with the assumption that global warming was occurring.

- Syukuro Manabe and Richard Wetherland considered the growing carbon dioxide concentration to be the most significant factor in strengthening the atmospheric greenhouse effect, to the extent that they gave an estimate of the expected temperature increase if that concentration were to double (between +1.3°C and +2.3°C for 2×300 ppm CO_2) [Manabe & Wetherland, 1967: p. 250].
- Kenneth Hare demonstrated that the decline in average temperature between 1940 and 1970 was not global; James Hansen and others agreed with the view that this colder period was temporary and confined only to the Northern Hemisphere [Hare, 1979[630]; Hansen et al., 1981: p. 961], while others revealed the limited cooling effect of aerosols from some sources as a possible reason for that temperature decline [Wang et al., 1976].[631]

Cause or effect? Concerning the relationship between global average surface air temperature and atmospheric carbon dioxide concentration, a heated discourse also erupted over which came first, that is, changes in which of the former variables lead to changes in the other. (Because there is also a 'reverse' mechanism, meaning that as temperatures rise, there is more water vapor accumulates in the atmosphere, and atmospheric emissions of carbon dioxide and methane may also escalate.) Other factors – such as decreasing surface albedo due to the reduction of snow and sea ice cover – would contribute to a further increase in surface temperature (as a positive 'feedback mechanism') until a new equilibrium state of the climate system is established.

- During the glaciation periods, the onset of a temperature decline may have triggered, among other effects, a slow change in the atmospheric carbon dioxide concentration in the same direction, which may have reinforced a further temperature decrease [Schneider, 1989[632]; Lorius et al., 1990].
- Compared to these previous 'adjustment' processes that lasted up to a few hundred years, the current situation is more rapidly changing and 'reversed'; that is, atmospheric carbon dioxide is increasing due to human activities, which leads to growing surface temperatures [Hansen et al.,

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[628] "The rise in temperature that began at the end of the last century stopped in about 1940, and a fall in temperature started. […] it should be suggested that a decrease in radiation after 1940 could also depend on the increase of dust in the atmosphere due to the man's activity." (p. 612)

[629] 'Eppur si': this refers to a phrase attributed to Galileo Galilei, according to which he considered the rotation of the Earth to be proven despite those who doubted it; there are examples of this kind of argument in other environmental contexts [Faragó, 2018b].

[630] "It is questionable, moreover, whether the trend is truly global. […] Calculated variations in the 5-year mean air temperature over the southern hemisphere […] show that temperatures generally rose between 1943 and 1975 […] the scattered SH data fail to support a hypothesis of continued global cooling since 1938." (p. 65)

[631] The argumentation was supported by "the likelihood that the potential counter-effect of atmospheric aerosols will be either sporadic (in the case of volcanic aerosols) or limited by the short lifetime of airborne particulates subject to fallout and rainout (in the case of tropospheric anthropogenic aerosols)". (p. 689)

[632] "At the maximum of the last Ice Age 18,000 years ago, CO_2 levels were roughly 25% lower than pre industrial values. […] whether the CO_2 level was a response to or caused the temperature changes is debated: CO_2 may have simply served as an amplifier or positive feedback mechanism for climate change". (p. 772)

2008].[633] Others estimated that this time it might take only a few decades for the temperature rise due to these carbon dioxide emissions to reach its maximum [Ricke & Caldeira, 2014].

The Cold War and military threats affecting the global climate. In the harsh 'political climate' of this period, a nuclear war between the two superpowers of the time could have caused a 'nuclear winter'.

- The first warnings of this danger appeared in the mid-1950s [Neumann, 1955[634]; Ayers, 1965[635]], but only the development of atmospheric circulation and climate models and the availability of higher-capacity computers made more accurate estimates possible from the 1970s onwards. Experts from both nuclear superpowers analyzed the risks of the social, economic, and environmental consequences of a possible mutual nuclear strike. Obviously, the outcomes of these risk analyses contributed to the conclusion of the 1972 nuclear arms limitation agreements. The concern was also reflected in the declaration adopted at the UN conference held that year: "Principle 26. Man and his environment must be spared the effects of nuclear weapons and all other means of mass destruction. States must strive to reach prompt agreement, in the relevant international organs, on the elimination and complete destruction of such weapons." [UNCHE, 1972]
- The US academic committee that conducted these risk assessments addressed the probable environmental implications of such a nuclear conflict in its first report: in their view, assuming nuclear explosions of the order of 10^4Mt, the decrease in global average temperature would be slight compared to the damage to the ozone layer [NAS, 1975: I/1. p. 6]. Paul Crutzen and John Birks came to a similar conclusion [Crutzen & Birks, 1982]. The 1983 TTAPS report [Turco et al., 1983] brought about a fundamental change in these assessments, but the vision of a 'nuclear winter' outlined therein was considered exaggerated by other researchers and refined to a 'nuclear autumn'.
- These 'US statements' were also followed by science-based 'SU statements' on this issue, which were introduced in a presentation by two academicians, Alexander Obukhov and Georgy Golitsyn, at a conference in Moscow in 1983. Others specified the possible effects of a nuclear war, including the extent of global cooling [Aleksandrov & Stenchikov, 1984][636] or how unstable the climate system could become over several years [Kondratyev, 1985, 1988].
- The findings of these scientific investigations contributed not only to the establishment of international expert cooperation on this extremely hazardous outcome with the support of ICSU and WMO but also to new nuclear arms limitation negotiations between the two nuclear powers. Given the outstanding importance of the topic, the UN General Assembly adopted a resolution on this, based on which the first comprehensive international assessment was completed in 1985 [UN, 1985].[637] The authors of the volume prepared under the aegis of ICSU also thoroughly

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[633] *Pleistocene epoch*: "Let us consider climate change averaged over a few thousand years […]. GHG and surface albedo changes are mechanisms causing the large global climate changes […], but they do not initiate these climate swings. Instead changes of GHGs and sea level (a measure of ice sheet size) lag temperature change by several hundred years […]. GHG and surface albedo changes are positive climate feedbacks. Major glacial-interglacial climate swings are instigated by slow changes of Earth's orbit". *Anthropocene era*: "Human-made global climate forcings now prevail over natural forcings […]. If we stay our present course, using fossil fuels to feed a growing appetite for energy-intensive life styles, we will soon leave the climate of the Holocene, the world of prior human history. The eventual response to doubling pre-industrial atmospheric CO_2 likely would be a nearly ice-free planet".

[634] "[T]echniques that would also lend themselves to forms of climatic warfare as yet unimagined" (p. 515).

[635] "Qualitative considerations suggest that, on balance, the lower troposphere, and the surface of the ground, would be substantially cooler and drier for some time (weeks) after the detonation of a large number nuclear weapons" (p. 116).

[636] "Проведенные численные эксперименты показывают, что в условиях длительного затемнения Северного полушария температура над его континентами падает на величину порядка 10° […]. Южное полушарие пострадает меньше. […] Индуцированные затемнением изменения климата смогут затухнуть, по-видимому, за время порядка двух лет." (p. 144)

[637] One of the experts invited to take part in the compilation of this assessment was Gyula Bora, Vice-Rector of the Budapest University of Economics (UNGA A/43/351, 1988).

discussed the hypothetical environmental implications of a nuclear war [Pittock et al., 1986]. The analysis published in connection with the World Climate Research Programme specifically focused on the likely climate consequences [Golitsyn & Phillips, 1986]. During these Cold War years, the possibility of 'climate warfare', or limited-range, deliberate climate modification intended to harm a country considered an enemy, was also raised; the international convention prohibiting environmental modification by military means was aimed at avoiding such destructive interventions [ENMOD, 1976].[638]

4.1.3. Growing scientific certainty

> A better understanding of the functioning and changes in the climate system presented the scientific community with a major challenge and, at the same time, responsibilities in view of the potentially severe impacts of human interventions on the natural order of this vast system. The exploration of these processes and relationships was facilitated by the expansion of observational information, more advanced modeling, and other investigative methods.

Main properties of the key long- and short-lived greenhouse gases. In order to more profoundly ascertain the potential climate-regulating effects of these ('well-mixed' in the atmosphere) gases, it became essential, above all, to obtain more precise knowledge of their changing atmospheric concentrations, starting with carbon dioxide [Revelle & Suess, 1957].[639]

- These measurements were begun by Charles Keeling in 1958 at the Mauna Loa Observatory (MLO) using the highest-quality spectrophotometer at the time. Derived from these and other data collected from different locations (e.g., Antarctica), it was revealed that there had already been a minor but uneven increase in atmospheric carbon dioxide concentrations [Keeling, 1960: p. 203]. Bolin and Eriksson, using assumptions about carbon dioxide emissions derived from the increasing combustion of fossil fuels, estimated the atmospheric content of this trace gas in 2000 to be between +25% and +40% above pre-industrial levels (the actual figure turned out to be around +30%) [Bolin & Eriksson, 1958: p. 141].
- A few years later, seeing the even clearer trend, the United States President's Science Advisory Committee discussed this topic, taking into account the report of Revelle and his colleagues in which they predicted the possibility of further increases in the atmospheric carbon dioxide concentration and resulting climate change [Revelle et al., 1965].[640] In addition to carbon dioxide, measurements of several other greenhouse gases also began at MLO and elsewhere in the world. The abundance of these gases in the atmosphere has been rising ever since.
- In order to better comprehend these processes, it was necessary to assess more thoroughly the radiative transfer properties of the atmospheric trace elements, their contribution to the greenhouse effect ('radiative forcing') and its changes, and the emissions from various natural and anthropogenic sources. Furthermore, it was essential to arrive at a more precise determination

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[638] "[T]he term 'environmental modification techniques' refers to any technique for changing – through the deliberate manipulation of natural processes – the dynamics, composition or structure of the earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space. […] The provisions of this Convention shall not hinder the use of environmental modification techniques for peaceful purposes".

[639] "Present data on the total amount of CO_2 in the atmosphere […] are insufficient to give an accurate base line for measurement of future changes". (p. 26)

[640] "Through his worldwide industrial civilization, Man is unwittingly conducting a vast geophysical experiment. Within a few generations he is burning the fossil fuels that slowly accumulated in the earth over the past 500 million years. […] The climatic changes that may be produced by the increased CO_2 content could be deleterious from the point of view of human beings." (p. 126)

of their environmental cycles [Archer & Brovkin, 2008[641]; Ciais et al., 2013[642]]. All of this was of crucial importance for comprehending the accumulation of these gases in the atmosphere, clarifying its causes, estimating its future rate, and 'foreseeing' the potential environmental and socioeconomic implications. In this context, knowledge about carbon dioxide emissions and accumulation in the atmosphere was particularly essential not only from a scientific point of view but also for international climate policies (in view of the intra- and intergenerational responsibility for and long-term aspects of this global environmental pressure) due to the extremely long atmospheric 'lifetime' of some of the emitted quantity of this gas (before it is removed from the atmosphere and e.g., absorbed in the ocean or by plants): "CO_2 has multiple residence times in the atmosphere from one year to many thousands of years […], and N_2O has a mean lifetime of 116 years. They are both long-lived GHGs, while CH_4 has a lifetime of 9.0 years and is considered a short-lived GHG" [IPCC/WG-I, 2021: p. 5-47].

A new era of global climate change research evolved from the 1970s onwards, with more and better global-level information available, inter alia, on the emission sources of the greenhouse gases and the key climatic elements, and with the realization that a global-level environmental change might be underway.

- When Keeling was faced with the upward trend in atmospheric carbon dioxide concentrations based on data from the first decade identified by more accurate measurements, he even then projected a dramatic scenario for humanity: "twenty-first century […] the people living then, along with their other troubles, may also face the threat of climatic change brought about by an uncontrolled increase in atmospheric CO_2 from fossil fuels." [Keeling, 1970: p. 17]. Bolin and Bischof refined the estimates, indicated directions for further research, and suggested that a review of fossil fuel-based energy supplies may be necessary [Bolin & Bischof, 1970].[643] According to Budyko, in addition to carbon dioxide emissions, heat pollution is also an important factor. Moreover, he considered it urgent to deal with the impacts of economic development on the climate to enable addressing them in due time [Budyko, 1972].[644] Schneider and Mesirov reviewed pre-existing methodological approaches and their initial results and considered that some response measures were urgent due to the likely climate change [Schneider & Mesirov, 1976].[645]
- This research was therefore carried out on an increasingly wider scale; in addition to American and Russian experts, the Swedish Bert Bolin played a prominent role in this [Bolin et al., 1977]. William Kellogg characterized the new situation this way: "The world has progressed a long way in the century since Tyndall, Chamberlin, and Arrhenius made those first tentative suggestions about mankind's ability to change the global climate. By far the biggest advances in the evolution

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[641] "Confusion of net versus gross carbon fluxes can also lead to a conclusion of a short CO_2 lifetime. The lifetime of an individual CO_2 molecule released to the atmosphere may be only a few years, because of exchange fluxes with the ocean and with the terrestrial biota. […] However, exchange of carbon has no impact on climate, only net uptake of carbon. The lifetime of climate impacts from CO_2 release will be much longer than the lifetime of the particular CO_2 molecules we release. The 5-year low end estimate of the lifetime of CO_2 from the 2001 IPCC must be an exchange lifetime, rather than an invasion lifetime." (p. 293)

[642] "Carbon dioxide (CO_2), after it is emitted into the atmosphere, is firstly rapidly distributed between atmosphere, the upper ocean and vegetation. Subsequently, the carbon continues to be moved between the different reservoirs of the global carbon cycle, such as soils, the deeper ocean and rocks. Some of these exchanges occur very slowly. Depending on the amount of CO_2 released, between 15% and 40% will remain in the atmosphere for up to 2000 years, after which a new balance is established between the atmosphere, the land biosphere and the ocean." (p. 544)

[643] "[W]e still know very little of how rapidly the industrial CO_2 disappears into the biosphere and the oceans. […] If significant climatic changes would become apparent as a result of such an increase of atmospheric CO_2, it might of course turn out to be necessary to switch to other energy sources than fossil fuels." (p. 440)

[644] "При существующих темпах хозяйственного развития деятельность человека может в близком будущем привести к изменениям глобального климата." (p. 44)

[645] "There are various estimates of the response of globally averaged surface temperatures to a doubling of CO_2 […]. Although these predictions vary considerably, probably the best order of magnitude estimate that can be made today is for a surface warming by some 1.5 to 3°K globally." (p. 180)

of an awareness that this could really be true was in the 1970s." [Kellogg, 1987: p. 132] The investigations continued with the participation of representatives of numerous scientific disciplines, and starting from the late 1970s, forums and institutional frameworks for their international cooperation were also created. All these views about further research directions were reinforced by the fact that global average surface temperatures had started to rise again since the 1970s at varying rates (apart from a few years of stagnation in this trend in the first decade of the present century, which was explained in various ways [Trenberth, 2015]). It also became more evident that already recognized extremely multifactorial relationships need to be further examined to ensure that possible future changes in the climate system, along with their consequences, could be more accurately delineated.

- The representatives of the scientific community in Hungary also turned their attention to the international developments of the 1970s regarding the climate change problematic and began to address it. Pál Ambrózy followed this international process from the early 1970s [Ambrózy, 1971]; then, together with Rudolf Czelnai and Gusztáv Götz, they provided an overview of the recent research developments and expressed their views on this matter, including their concerns about the possible adverse consequences of climate change and the urgent need for further scientific investigation [Ambrózy et al., 1977].[646] Zoltán Dobosi and László Felméri, on the other hand, were skeptical that global climate change caused by human activities had begun [Dobosi & Felméri, 1977].[647] Ferenc Probáld completed the manuscript of a publication in 1979, in which he discussed the risks due to the increasing level of atmospheric carbon dioxide and the feedback mechanisms [Probáld, 1981].[648] Observations and the respective analyses began in 1981 regarding carbon dioxide, then other greenhouse gases; László Haszpra did a lot towards the development of these measurements and the presentation of their history [Haszpra et al., 2010; Haszpra, 2012]. The role of aerosols in affecting climate was also explored, starting with Ernő Mészáros, who already emphasized this phenomenon in his book on atmospheric chemistry [Mészáros, 1977]. Two decades later, this effect could be and was assessed more thoroughly, about which we will only cite one conclusion here: "The atmospheric residence time of sulfate (and other particles) […] is only a few days. […] In contrast, greenhouse gases with lifetimes of tens, often hundreds of years, have enough time to mix throughout the atmosphere and cause global warming." [Mészáros, 1996: p. 9; Mészáros, 1999] These investigations were continued by László Bozó and András Gelencsér; their studies addressed both the air quality and climatic aspects associated with particulate matters [Bozó 2001; Bozó et al., 2006; Gelencsér, 2004; 2014].

The beginnings and development of climate modeling. The conditions for the comprehensive analysis of the climate system using concrete calculations, i.e., for advanced numerical climate modeling, were created and became available from the 1970s onward. These involved: (i) better knowledge of the main components, properties, and interactions of this global system, (ii) their description using mathematical-physical tools (equations), (iii) more detailed observational data, and (iv) computers with sufficient capacity to run the relevant numerical models. The processor speed of computers reached a 'historic' level (1 MIPS) by 1970, and the very first customer of the first

[646] "What has been the effect of human activity on climate in the past and what will it be in the future? How might the combined effect of natural and anthropogenic factors manifest itself in the future? […] is humanity in a position to reverse adverse climate changes if necessary?" (p. 56)

[647] "The sharp distinction between climate change and climate variability does not make much sense, because even if, for example, the observational data in the current period showed a unidirectional change, if we do not know the cause, we cannot decide whether it is a unidirectional change […] or not. […] human work in transforming nature can also result in climate change. However, until now this has been microclimatic or at most mesoclimatic in scale". (p. 216)

[648] "The increase in the atmospheric carbon dioxide stock is undoubtedly causing a slight warming of the climate. However, such a disruption of the delicate balance of the climate system gives rise to further climatic processes and sets off a veritable chain reaction." (p. 107)

supercomputer (CRAY-1, with a speed of nearly 100 MIPS) was a US research center dealing with numerical climate models.[649]

- The first numerical models were based on simplified global energy balance approaches. Then theoretical global atmospheric circulation models became the basis for the creation of more advanced numerical versions, and with these, 'sensitivity' calculations could already be performed, for instance, to estimate the consequences of a hypothetical increase in atmospheric carbon dioxide content [Manabe & Wetherald, 1967].
- Over time, a whole hierarchy of models emerged, including models for describing interactions between the atmospheric and some ocean processes (the precursors of the future 'coupled' atmosphere-ocean models), but all these still were founded on tremendous simplifications [Schneider & Dickinson, 1974].[650] Incorporating all the important components and feedback mechanisms of the climate system (e.g., those related to clouds) into such models would have required even better computers. This explains why other simpler – stochastic, statistical-dynamic – model types also appeared [Hasselman, 1976; Saltzman, 1978; Faragó, 1978].
- In the following decade, the 'carbon dioxide problem' was analyzed by models that could already describe all the key components of the entire system, but it became apparent that there were other conditions for carrying out more accurate calculations [Kellogg, 1987].[651] Since then, further model development and impact assessments have continued unabated in many scientific centers.[652] This cooperation rapidly expanded among research groups and institutions from the mid-1980s on, and its results led to the better acceptance of the possibility of anthropogenic climate change by policymakers and the general public and to the beginning of the development of international climate policy responses.
- International modeling developments and numerical experiments aroused the interest of Hungarian researchers, as well. At a conference dedicated to the modeling of atmospheric processes in 1976, the presentation of Pál Ambrózy, Rudolf Czelnai, and Gusztáv Götz, followed by a more detailed paper, dealt with the theoretical issues of climate modeling [Ambrózy et al., 1977]. The authors recognized the complexity of this task: "Prognostic models should be constructed that allow for the prediction, at least in a statistical sense, of climate changes and trends over timescales ranging from a month to several centuries, and for the simulation of the effects of human activity […]. There can be no doubt about the importance of this objective, but it is also likely that the task of climate prediction can be ranked among the most difficult and complex scientific problems ever posed." Further theoretical studies discussed the importance and components of numeric modeling on a theoretical basis [Götz et al., 1978; Faragó, 1979; Götz, 1981; Faragó, 1981a]; then came publications whose authors already reported already on numerical models, simulations, their results, and the need to further develop these approaches [Mika, 1981; Pálvölgyi, 1985; Práger et al., 1986; Práger & Pálvölgyi, 1989; Szalai, 1989; Bartholy et al., 1996]. Later on, involvement in international cooperation greatly facilitated the climate modeling activities of the Hungarian experts.

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[649] The author of this book was a participant of a US-Hungarian scientific program in the 1980s; at that time, he was able to 'meet' with the even more powerful successor of the aforementioned computer at the US National Center for Atmospheric Research (NCAR).

[650] "[E]ven today we possess much of the scientific information required to construct models of our present climate and to identify the dominant physical processes of climate change. Such climate models will be indispensable tools for the understanding and ultimate prediction of climate change, but these tools are as yet unsharpened". (p. 488)

[651] "Our mathematical models of the global climate system are getting better and better, as both human ingenuity and increasingly fast computers allow us to take more physical factors and interactions into account. However, the spatial resolution of the best current climate models is still about 400 x 400 kilometers […], and this barely begins to give us some insight into what might happen regionally". (p. 128)

[652] These include, for example institutes such as the American NCAR and Russian GGO (where climate modeling started long ago), moreover the British HCCPR (since 1990) and the German PIK (since 1992). (NCAR: National Center for Atmospheric Research; HCCPR: Hadley Centre for Climate Prediction and Research; GGO: Главная Геофизическая Обсерватория; PIK: Potsdam Institut für Klimafolgenforschung).

* * *

Discovering the functioning of the global climate system, identifying the natural and human-caused factors that are likely to influence its state, and analyzing the possible consequences took a long time. First of all, understanding the composition of the atmosphere, its radiation transmission properties, and the greenhouse effect, and recognizing the changes in the state of the climate system caused by natural driving forces was crucial before other researchers could later assess the gradually increasing human interventions and their effects on the state of this system. The stages and turns of the scientific research activities that took place during the 19th century and in the first decades of the 20th century – amidst sharp debates – clearly show how the growth and refinement of knowledge can unfold through the critical consideration of earlier and newer scientific results, and how essential the development of observational techniques and theoretical methods is for this. It has become increasingly clear that this global environmental system and the factors driving its variability and long-term changes are much more complex than the scientific community believed until the 1940s. It is apparent that more precise procedures were needed to confirm or reject, among other things, the 'carbon dioxide theory'. Accelerated and diversified research since the mid-20th century further demonstrated that the changes in the state of this complex system and the causal relationships cannot be analyzed and interpreted in an oversimplified manner, limited to one or a few factors and interactions. Even then, the advanced observational and computational capabilities and environmental and other specialist knowledge required for complex and more in-depth studies had not yet reached the level where more substantiated scientific conclusions could be formed about the hazardous effects of human activities on the climate system. By the 1980s, however, not only was the diversity of factors and forms of feedback mechanisms influencing the state of this system and acting on different time scales sufficiently well known, but models were also rapidly developing with which much better sensitivity and predictability experiments could be conducted. These strengthened the scientific certainty that human effects on the Earth's climate could have increasingly dangerous environmental and social consequences and the realization that more effective cooperation between scientists was essential for moving forward.

4.2. INTERNATIONAL COOPERATION FRAMEWORKS FOR CLIMATE SYSTEM OBSERVATION AND RESEARCH

Since the mid-19th century, cooperation has gradually evolved for the purpose of observing the components of the climate system on a global scale, analyzing the large amount of information thereby obtained, and examining the shorter- and longer-term climate changes and their causes and impacts. These international and interdisciplinary developments have become essential for (i) understanding the functioning of this vast environmental system and the dangerous progression of its state under the influence of various natural and/or human driving forces, and (ii) formulating well-founded recommendations to mitigate the latter and prepare for the seemingly already inevitable adverse consequences.

4.2.1. Global monitoring of the climate system

The expansion of climate observations has led to the establishment of a global monitoring system after nearly a century and a half. Without the information derived from this network, it would not have been possible to identify changes in the state of the Earth's climate with sufficient accuracy or develop and test (numerical) models of the climate system.

The expedience of expanding observations of basic climate elements to regional and then continental levels arose in the second half of the 19th century, but they became global in scale – supplemented by atmospheric physics and chemistry measurements – only in the 1960s.

- This process began in the 1870s with the founding of the International Meteorological Organization, but the first international climate station network and database was only created in the early 20th century based on the proposal of one of the discoverers of the stratosphere, Léon de Bort. Without this, Callendar would not have been able to make his first calculations of the relationship between atmospheric carbon dioxide and average surface temperature (although he could only rely on a series of not very precise measurement data about CO_2-concentrations) [Callendar, 1938: pp. 224, 234].
- At an international meeting in Stockholm, participants agreed that the climate-related 'carbon dioxide theory' could not be proven without more adequate data on changes in atmospheric concentrations of this trace gas, and that the most reliable ('reference') measurements should be made far from any nearby interfering emission sources (e.g., industrial plants emitting CO_2) [Eriksson, 1954].[653] By taking into consideration this criterion, as a U.S. contribution to the program of the International Geophysical Year, precise carbon dioxide measurements began at the Mauna Loa Observatory (MLO) in 1957.
- Following UN Resolution 1721 (XVI) of 1961, the development of a Global Observing System (WWW-GOS) was launched in 1963, and later – including climatological observations – it was transformed into an integrated system (WIGOS)[654] [Zillmann, 2009]. Measurements of the composition of the atmosphere, and greenhouse gases in particular, followed separate 'organizational paths' for a while but then these merged into a global network when, starting in 1967, a laboratory[655] in the USA undertook to determine and publish data on greenhouse gas concentrations from samples sent from air chemistry stations around the world. In 1969, the Background Air Pollution Monitoring Network (BAPMoN) was organized and continued to operate as the Global Atmosphere Watch (GAW) from 1989 onwards, incorporating ozone measurements, too.

The global climate monitoring system. Observational data on the global environment and, as part of it, data reflecting the state of the climate system were indispensable for climate change research, as well as defining international climate policy goals and measures, and then evaluating their implementation.

- Several international organizations[656] agreed to set up the Global Climate Observing System in 1992, specifically for assisting climate change research [GCOS, 1992; Karl et al., 1995[657]].

- The need for such a system arose at the Second World Climate Conference in 1990 and it is no coincidence that the aforementioned agreement on its setting up was concluded shortly before the adoption of the *UN Framework Convention on Climate Change*. Somewhat later, the development of a European regional greenhouse gas monitoring system was also decided on [Haszpra, 2011a].

[653] "[P]laces with slight climatic variations and remote from any kind of atmospheric disturbances which may give rise to local changes are most suitable. Probably the most ideal place would be somewhere in the middle of the Sahara desert, and it was recommended to plan for such a station in the future. Another possible place would be Hawaii if samples were taken above the trade-wind inversion". (p. 305)

[654] WWW-GOS: World Weather Watch: Global Observing System; WMO Integrated Global Observing System (WIGOS).

[655] NOAA/ESRL/GML.

[656] ICSU, UNEP, UNESCO-IOC, WMO.

[657] "The development of a GCOS offers the opportunity for scientists to do something about existing observing deficiencies in light of the importance of documenting long-term climate changes that may already affected by anthropogenic changes of composition and land use as well as other naturally occurring changes." (p. 136)

4.2.2. Scientific cooperation in climate change research

The two main milestones in the new phase of the examination of the global climate system starting in the 1970s were the World Climate Program approved in 1979 at the international climate conference in Geneva and the formation of the Intergovernmental Panel on Climate Change (IPCC) in 1988. One of the key purposes for the latter's creation was to establish a direct interface and 'dialogue' between representatives of science and politics. Since then, this institutional system has expanded further, as has the scope of knowledge about the climatic processes.

The beginnings of international research cooperation. Due to the controversy surrounding the 'halt' of warming between 1940 and 1970, as well as the limited quantity and quality of global-scale data from the observational system at that time, and the lack of sufficient computing capacity for numerical modeling, researchers initially could only agree on the *possibility* of the global climate influence of human activities and the need to improve observational systems and expand these examinations. These findings were reiterated in the presentations at a Stockholm meeting on climate science [SMIC, 1971] and in the recommendations on climate-related research approved at the UN environment conference held the following year. These initiatives catalyzed further concrete steps.

- At an expert gathering held in Budapest in 1974, it was decided that the Global Atmospheric Research Programme (GARP),[658] which had been running for many years, should also have a Climate Dynamics Subprogram [Perry, 1975; Ambrózy et al., 1977]. Its objectives were approved at a follow-up conference in Wijk, Sweden [GARP, 1975].[659]
- An international research report and a 1976 WMO statement also referred to the need to expand investigations into potential anthropogenic climate change [Gibbs et al., 1976; WMO, 1976]. The latter already revealed that the global warming effect of carbon dioxide emissions from the combustion of fossil fuels was much more likely than previously thought.[660]

The first World Climate Conference in 1979 (Geneva) and the launch of the World Climate Programme marked the beginning of global efforts to explore the impacts of human activities on the climate system. The milder 'world political climate' at the time was an important factor that facilitated the participation of leaders of numerous professional institutions from all regions of the world in this event.

- The Geneva conference declaration addressed concerns that increasing atmospheric carbon dioxide emissions from human activities could contribute to gradual warming, as well as the lack of sufficient knowledge about this process and its consequences [WMO, 1979[661]]. (The problem of environmental acidification and the related 1979 pan-European convention similarly reflected

[658] The development of GARP was mandated by UN Resolution 1721 (XVI) of 1961.

[659] Introduction: "it is not clear whether man's activities have yet increased to such a level that they have contributed significantly to the largescale variations of climate as recorded during the last decades. […] The assessment of the degree of predictability of both natural and man-produced fluctuations is therefore of considerable significance." (p. 26)

[660] "Burning of oil and coal increases the amount of carbon dioxide in the atmosphere and this could produce a long-term warming […]. The release of chemicals (for example, chlorofluoromethanes) and the increase in the dust content in the atmosphere as a result of man's activities, if not checked, might also alter the climate. […] Improved understanding of and improved ability to predict the impact of man's activities on the global climate is needed in view of their possible consequences." (p. 17)

[661] "There is serious concern that the continued expansion of man's activities on earth may cause significant extended regional and even global changes of climate. This possibility adds further urgency to the need for global co-operation to explore the possible future course of global climate […] we can say with some confidence that the burning of fossil fuels, deforestation, and changes of land use have increased the amount of carbon dioxide in the atmosphere […]. Carbon dioxide plays a fundamental role in determining the temperature of the earth's atmosphere, and it appears plausible that an increased amount of carbon dioxide in the atmosphere can contribute to a gradual warming of the lower atmosphere, […] but the details of the changes are still poorly understood." (pp. 3-4)

the still considerable scientific uncertainty regarding the causality of this harmful phenomenon, but efforts to overcome this 'deficit' through more in-depth research and a temporary reliance on the precautionary principle provided an example for the scientific approach to the 'climate change problematic' [Faragó, 2016a].)

- The main goals of the World Climate Programme were to foster (i) research into the sensitivity and predictability of the climate system (by means of various numerical climate models), (ii) assessments of the possible impacts of changes in the state of this system, (iii) the development of climate observation and data processing networks, and (iv) the utilization of the information derived from latter, among other things, for preparing for the presumed/expected changes in the climatic and related environmental conditions. The program consisted of four components respectively dedicated to climate research, impact assessment, climate data, and the application of growing scientific knowledge on this matter.[662] According to Rudolf Czelnai,[663] in addition to the fact that the Geneva conference resulted in the birth of the World Climate Programme, it was "the first major gathering of researchers who were able to add something important to the topic." [Czelnai, 2006][664]

Implementation and further development of the international climate research program. The initial experiences with the GARP Climate Dynamics Subprogramme were taken into account in the decision to continue and expand this research collaboration.

- The World Climate Research Programme (WCRP), which began in 1979 with much broader goals, was coordinated by the WMO together with the ICSU. In parallel, the execution of other components of the World Climate Programme also started.[665] Due to the expanding and improving outcomes of this program, from the second half of the 1980s onwards, mitigating the risk of anthropogenic climate change and establishing measures to promote adaptation were already on the agenda of international cooperation.

- The scientific community also paid more attention to other processes of 'environmental globalization' interrelated with climate change such as the threat to the ozone layer and the decline in biodiversity. Within the framework of ICSU, the need to design an International Geosphere-Biosphere Programme (IGBP) arose for the study of the completeness and interrelationships of natural and human-caused influences on the state of the Earth's environment [ICSU, 1987].[666]

The World Climate Program facilitated comprehensive research on the climate system and, to this end, the effective participation and cooperation of researchers representing all respective scientific disciplines.

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[662] These components included the World Climate Research Programme (WCRP), World Climate Impacts Programme (WCIP), World Climate Data Programme (WCDP), World Climate Applications Programme (WCAP).

[663] Academician Rudolf Czelnai was the Deputy Secretary-General of WMO (1985-1992).

[664] These international developments soon aroused interest in Hungary as well: in 1980, the theme of a scientific conference held at the headquarters of the Hungarian Academy of Sciences (HAS) was inspired by the world program [Götz, 1981] and a scientific body of the HAS was set up to assess the evolving international climate science cooperation and analyze the possibilities associated with the Hungarian connection to it [Faragó, 1981a, 1981b].

[665] WMO was responsible for coordinating the data and application programs, and UNEP for the impact assessment program, but other organizations also contributed to its implementation (e.g., FAO, IIASA).

[666] "A primary goal of the Programme is to advance our ability to predict change in the global environment. The development of this capability will require cooperative and complementary efforts with climate modellers in order to incorporate the appropriate level of understanding for relevant global biological, geological, and chemical processes into physical models of the earth system." (pp. 2-3) The IGBP was succeeded by the truly holistic 'Future Earth' scientific (framework) program from 2015, but the WCRP remained an important component of this as well.

- After the Second World Climate Conference (1990), the international climate program was renewed, its components were expanded,[667] and many more specialists from all regions and working in various fields were involved in this collaboration.
- In addition to the analysis of human activities affecting the climate system, greater emphasis was placed on identifying possible policy responses to prevent/mitigate hazardous changes in climatic conditions and on preparing for (i.e., avoiding/lessening) their potential adverse impacts.[668] The application program was also revised, recognizing how important the awareness of and information about climate variability and change is, for example, for agriculture and water management.
- The data program became much broader as environmental observations were considerably expanded by means of new (e.g., remote sensing) measurement techniques, and then the possibilities for studying the climate system were further enlarged by the establishment of the Global Earth Observation System of Systems (GEOSS) from 2005 onwards.
- All these observational and research program developments contributed to the acceleration of international climate policy cooperation from the early 1990s onwards, based on growing climate-change-related scientific knowledge.

4.2.3. Climate science and climate policy: institutionalizing the science-policy interface

> Participants of an international expert conference (Villach, November 1980) concluded that it was not enough to consider the theoretical possibility of a change in the state of the global climate system – primarily resulting from the increasing use of fossil fuels – but that research into the possible consequences should also be accelerated in order to inform decision-makers of the need to consider appropriate measures [WCP, 1981].[669] Scientific knowledge has expanded greatly regarding the functioning of this extremely complex environmental system, its changes due to natural forces and human activities acting on different time scales and extents, and the possible consequences of such changes, but still, the degree of scientific uncertainty about all these issues remained quite significant. Nevertheless, in the spirit of precaution, it seemed appropriate to consider some initial measures, primarily to mitigate the most likely anthropogenic effects on the climate system. For the same reasons of 'uncertainty' (as before), counterarguments also emerged, i.e., others questioned the adequacy of the models at the time and the validity of the anthropogenic-climate-change conclusions [Ellsaesser, 1984].

Had the time come to formulate international policies and agreements on climate change? The convention for the protection of the ozone layer was adopted in the spring of 1985. This not only became a direct reference and precedent for experts in both the scientific and political circles that were dealing with the threat of climate change, but also a clear 'incentive' for moving forward as soon as possible in this matter by laying the foundation for climate policies and a legal framework for them.

- According to the declaration adopted at the international expert meeting (October 1985, and again in Villach), the understanding of the atmospheric 'greenhouse problem' had reached a level where

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[667] WCIRP: World Climate Impacts Assessment and Response Strategies Programme; WCASP: World Climate Applications and Services Programme; WCDMP: World Climate Data and Monitoring Programme.

[668] The author of this book became a member of the Scientific Advisory Committee (UNEP-SAC) of this program in 1992.

[669] "It is essential that the research proposed here be undertaken as a matter of urgency so as to put on a firmer scientific basis any intergovernmental action that may be required to accommodate a potential situation with which the world has not yet been confronted." (p. 3)

– despite the remaining uncertainties – scientists and politicians should address this matter, explore possibilities for prevention and adaptation, as well as the development of a global convention [WCP, 1986[670]; Bolin et al., 1986; KTM-OMSZ, 1990].

- At the next forums in 1987 (Villach, Bellagio), in addition to clarifying the substance of proposed immediate measures, the participants agreed that an intergovernmental mechanism was needed and urged the start of the preparation of an international legal instrument to define climate policy actions [Jäger, 1988].[671] The 1988 Toronto conference brought together scientists and government officials from some forty countries, who reaffirmed earlier proposals for global institutional and regulatory courses of action; moreover, they came up with concrete greenhouse gas emission reduction targets [WMO, 1989]. It is remarkable to recall these quantified proposals (and compare them to those later adopted during climate policy negotiations in the 1990s): "Stabilizing the atmospheric concentrations of CO_2 is an imperative goal. It is currently estimated to require reductions of more than 50% from present emission levels. […] Reduce CO_2 emissions by approximately 20% of 1988 levels by the year 2005 as an initial global goal. Clearly, the industrialized nations have a responsibility to lead the way" (Declaration: p. 6).
- The World Commission on Environment and Development also dealt with this global subject in its report and saw the need for the closer cooperation of governments and the scientific community, the determination of emission reduction and adaptation policies, and the elaboration of a convention devoted to climate change [WCED, 1987].[672] (The composition of this committee was exemplary in indicating the importance of the dialogue between representatives of science and politics: its leaders were the Norwegian Prime Minister Gro Harlem Brundtland and the Sudanese Deputy Prime Minister Mansour Khalid, while its members were politicians and scientists from all the UN regions, including István Láng the then Secretary General of the Hungarian Academy of Sciences.)
- The commitment to accelerating the definition of climate policy responses and formulating a climate change agreement was expressed in the statement adopted at the Second World Climate Conference[673] and the joint declaration of the ministers [Jäger & Ferguson, 1991]. Here are two especially remarkable excerpts from these documents: "The development of policy regarding climate change requires on the part of policy makers an understanding of the underlying science and a weighing of the scientific uncertainties associated with the prediction of climate change and its likely impacts. An important aspect of future work is therefore a continued dialogue between scientists and policy makers." (Conference Statement: p. 503). "We call for negotiations on a framework convention on climate change to begin without delay". (Ministerial Declaration: p. 539).

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[670] "Major uncertainties remain […]. Nevertheless, the understanding of the greenhouse question is sufficiently developed that scientists and policy-makers should begin an active collaboration to explore the effectiveness of alternative policies and adjustments. […] UNEP, WMO and ICSU should […] initiate, if deemed necessary, consideration of a global convention." (pp. 3-4)

[671] "Examination by organizations, including the intergovernmental mechanism to be constituted by the WMO and UNEP in 1988, of the need for an agreement on a law of the atmosphere as a global commons or the need to move towards a convention along the lines of that developed for ozone." (p. v)

[672] "A lot of policy development work is needed. This should proceed hand in hand with accelerated research to reduce remaining scientific uncertainties. Nations urgently need to formulate and agree upon management policies for all environmentally reactive chemicals released into the atmosphere by human activities, particularly those that can influence the radiation balance on Earth. Governments should initiate discussions leading to a convention on this matter." (p. 177)

[673] On the Hungarian side, Emánuel Antal, István Láng, Ödön Starosolszky and Judit Vásárhelyi participated in this conference, and a separate compilation presented the results of Hungarian climate science results to that point [Antal & Starosolszky, 1990]. The author of this book was requested by the WMO Deputy Secretary-General Rudolf Czelnai to write a review of the above-mentioned 1991 publication summarizing the key outcomes of the conference (WMO Bulletin, 41:4, pp. 486-487).

The Intergovernmental Panel on Climate Change (IPCC): a global institutional framework for facilitating the relationship between climate scientists and climate policy makers. This organization was established in 1988 as an *intergovernmental* forum for policymakers to discuss actions to be taken based on the essence and evaluation of the latest research results about anthropogenic climate change and its impacts, jointly compiled and summarized by representatives of various scientific disciplines [IPCC, 1988[674]; IPCC, 1998[675]]. (One of the 'precursors' of this panel was the ICSU-SCOPE, whose primary task was also to prepare a synthesis of already published research results about environmental problems.)

- The IPCC's operation has been based on the international collaboration of researchers nominated from all relevant fields and all regions of the world – however, it did not become a 'classical' scientific institution, but an *intergovernmental* organization for the facilitation of (climate) policy decision-making at the global level [Bolin, 2007[676]]. Its rules of procedure and the *Summaries for Policymakers* of the comprehensive scientific assessment reports were approved by government representatives (based on a number of compromises reached in consultation with the researchers). This is how all reports on climate change to date were created, starting with the first one, which was finalized in 1990. The Panel's activities since its founding were recognized with the Nobel Peace Prize in 2007.[677]

- In addition to discussing the different perspectives of climate science and politics, Bert Bolin, the first chairman of the IPCC, also gave an additional argument for this specific operating procedure of the IPCC, namely: "many countries, especially developing countries, simply don't trust assessments in which their scientists and policymakers have not participated" [Schneider, 1991: p. 25]. Apparently, for the same reason, the IPCC 'model' (and to some extent, the aforementioned earlier ICSU-SCOPE 'model') for the science-policy interface influenced the way in which the scientific advisory body to the climate convention (SBSTA) was established in 1992, the body with a similar mandate on biodiversity in the same year (SBSTTA), the intergovernmental organization on biodiversity (IPBES) in 2012 – and plans are currently underway to organize such a panel on chemicals (SPP).[678]

- These international climate science developments also motivated the Hungarian experts. Climate-change-related research studies were included in comprehensive volumes [KTM-OMSZ, 1990, 1991; MTA, 2010a] and the summaries of IPCC reports were published (in Hungarian) [FFB, 1996; Védegylet, 2004; KvVM-OMSZ, 2007]. In addition, an academic program entitled 'Climate Change: Impacts and Responses' ('Vahava Project') was launched, in which many researchers participated and on the basis of which numerous recommendations were formulated [MTA, 2006; MTA, 2010b]. According to István Láng (the chief coordinator of the program): "the main methodological feature of the Vahava project was the large-scale systems synthesis.

[674] "The Panel agreed that its work included three main tasks: (i) Assessment of available scientific information on climate change; (ii) Assessment of environmental and socio-economic impacts of climate change; (iii) Formulation of response strategies." (p. 4)

[675] Principles Governing IPCC Work: "IPCC reports should be neutral with respect to policy, although they may need to deal objectively with scientific, technical and socio-economic factors relevant to the application of particular policies." (p. 21)

[676] "The climate change issue would ultimately not concern just the scientific community, but there would be a need to reach out to the public, stake-holders, decision-makers and politicians. A clear distinction had to be maintained between a basic scientific assessment of the state of knowledge on one hand, and political negotiations to reach agreements on policies and measures, on the other." (p. 62)

[677] From the Statement of the Norwegian Nobel Committee (Oct. 12, 2007): "Through the scientific reports it has issued over the past two decades, the IPCC has created an ever-broader informed consensus about the connection between human activities and global warming. Thousands of scientists and officials from over one hundred countries have collaborated to achieve greater certainty as to the scale of the warming. […] By awarding the Nobel Peace Prize for 2007 to the IPCC and Al Gore, the Norwegian Nobel Committee is seeking to contribute to a sharper focus on the processes and decisions that appear to be necessary to protect the world's future climate".

[678] Science-Policy Panel (SPP).

[…] In accordance with this methodology, an interdisciplinary approach and broad cooperation were needed, covering all relevant sectors." [Láng, 2010] Furthermore, two statements summarizing the views of the respective research teams on this hazardous process were published under the auspices of the Hungarian Academy of Sciences [MTA, 1991; MTA, 2009].[679] It should be noted that some Hungarian researchers questioned the validity of the theory of anthropogenic climate change.[680] A connection was also set up with the IPCC: Hungarian experts participated in the latter's activities and this prominent organization held its 2008 session in Budapest, on which occasion the National IPCC Committee (NIC) was formed.[681]

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The international scientific programs and organizations that provided a framework for cooperation between climate change researchers and facilitated their relationship with policymakers have greatly contributed to the exploration of this global-level problem, the broadening of observational information and research findings, as well as the general acknowledgment of this hazardous process. The various international and national science-policy panels/bodies established since 1988 have directly 'connected' science and policy actors and have become of paramount importance in understanding and acknowledging the threat of climate change and other related hazardous environmental issues. The content of their concise reports (typically called 'Summaries for Policymakers') and the methods of their adoption – based on consultation between representatives of science and governments – have been a guarantee that their findings and recommendations will be taken into account during international climate policy negotiations and decisions, as well as in national-level programs and action plans.

4.3. INTERNATIONAL CLIMATE POLICIES: PRINCIPLES, GOALS, AND COMMITMENTS

International climate policy cooperation has a history of several decades, the development of which has been based on the expansion of scientific knowledge about this global hazard. However, due to, among other things, the significant uncertainty about the causal relationships involved in this process and its potential implications, only very 'cautious' policy responses had emerged by the end of the 1980s. The international agreements adopted subsequently were already based on a relatively clear global climate protection objective, but the more specific, time-bound goals and the gradually 'tightening' obligations, measures and supplementary implementation tools were approved only at the cost of significant compromises. Consequently, they did not seem sufficient to achieve the

[679] Here are some highlights: "The climate is likely to undergo a change unprecedented in human history as a result of human activity. […] the present generation must take steps to avoid or at least mitigate the risks and consequences of climate change" [MTA, 1991]. "The rate of increase in greenhouse gas emissions may result in warming faster and more rapidly than the temperature increase observed in recent decades. […] There is broad scientific consensus that catastrophic consequences can still be prevented by significantly reducing emissions and preparing for the impacts" [MTA, 2009]. (The author of this book was a member of both the committees that prepared these statements.)

[680] Based on his theory and derivation, Ferenc Miskolczi cast doubt on the claim that the cause of global warming is the increase in the atmospheric concentration of greenhouse gases [Miskolczi, 2007: pp. 35-36]. László Szarka is also a strong critic of the anthropogenic climate change theory and has presented arguments to this effect in several articles [e.g., Szarka, 2010]. Other researchers have also expressed themselves in this debate, such as László Haszpra, who, referring to the IPCC, argued that the current climate change process can primarily be attributed to anthropogenic greenhouse gas emissions [Haszpra, 2011b].

[681] Some Hungarian experts were directly involved in the IPCC's activities between 1993 and 2010 (as co-authors, by contributing professional materials, as reviewers or conference participants): Judit Bartholy, Tibor Faragó, Tamás Jászay, János Mika, Tamás Pálvölgyi, Zoltán Somogyi, Ferenc L. Tóth, and Diana Ürge-Vorsatz. Of course, this also became possible for other researchers after 2010. The author of this book was the coordinator of Hungarian cooperation with the IPCC between 1993 and 2010, and in 2008 he initiated the establishment of the National IPCC Committee (NIC).

'ultimate' objective – above all, of halting the increase in atmospheric concentrations of greenhouse gases (GHGs) as soon as possible.

4.3.1. Clarifying the basics: Who is responsible? How certain is the hazardousness of this process? What can be done?

Following the recognition of the potential of some human activities to cause global climate change, the beginning of international climate policy cooperation aimed at curbing this process was marked by the above-mentioned UN resolution of 1988 and the subsequent ones of 1989 and 1990. These set out the main reasons and directions for coordinated actions and at the same time foreshadowed some future areas of conflict, which were reflected later – albeit in different formulations – in the 1992 *UN Framework Convention on Climate Change* (UNFCCC), in the complementary legal instruments in 1997 (Kyoto) and 2012 (Doha), as well as in the 2015 *Paris Agreement*.

Everyone is responsible for this hazard and everyone is affected by its consequences, but in very different ways and to very different degrees. Based on the findings achieved by the scientific community up to that point, by the end of the 1980s, the threat of anthropogenic climate change had become acknowledged and the fact that coordinated international actions were therefore needed that would take into account the specific situation of individual societies in relation to this matter [UN, 1988; UN, 1989].

- The principle of "common but differentiated responsibilities and respective capabilities" became one of the most important reference points of the 1992 *Convention*, based on which the most essential (initial) obligations for the Parties were determined. By adopting this, developed countries acknowledged that the largest share of historical and current global emissions of greenhouse gases had originated in their countries; consequently, "[they] should take the lead in combating climate change and the adverse effects thereof" [UNFCCC, 1992: Preamble and par. 3.1].
- After the entry into force of the 1997 *Kyoto Protocol*, the application of this principle from 2005 onwards became controversial and a kind of barrier to further cooperation, primarily between some large-GHG-emitting developed countries and some key developing countries whose economies were rapidly growing, which was accompanied by their increasing greenhouse gas emissions.

Wait for greater scientific certainty or act? The IPCC's first assessment report in 1990 and the 1990 UN resolution referring to it made it clear that there was already sufficient knowledge about the threat of anthropogenic climate change to develop a climate protection convention, but that the still remaining scientific uncertainty had to be taken into account [UN, 1990].[682]

- In view of the latter, the 1992 *Convention* was based on the precautionary principle and, accordingly, even the developed countries and some of the countries 'with economies in transition' (from the CEE region) only undertook to temporarily avoid an increase in their greenhouse gas emissions: "Each of these Parties shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions […], recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide

[682] The General Assembly "urging Governments and, as appropriate, intergovernmental and non-governmental organizations and scientific institutions, to collaborate in a concerted effort with the aim of preparing, as a matter of urgency, a framework convention on climate change […], taking into account the most up-to-date, sound scientific knowledge and any existing uncertainties".

and other greenhouse gases […] would contribute to such modification …" [UNFCCC, 1992: 4.2.(a)].

- In contrast, scientific knowledge advanced to such a degree over the next two and a half decades that the 2015 *Paris Agreement* did not either mention the remaining uncertainties nor the precautionary principle, but rather clearly prescribed a series of measures to reduce the risk and impacts of climate change [UNFCCC/PA, 2015: 2.1.(a), 4.4., 7.1-2.].

Mitigation or adaptation? Until the development of the international convention began, the emphasis was on preventing, or at least mitigating, anthropogenic climate change.

- The UN resolutions of 1988-1990 did not refer to preparing for possible changes in climatic conditions, but the 1992 *Convention* already addressed this issue. Negotiations on assuming differentiated responsibilities related to this dangerous process and the resulting emission regulation commitments were particularly difficult. However, developing countries, which were particularly vulnerable to the adverse effects of climate change and had borne much less historical and current responsibility for such emissions, considered measures for promoting adequate adaptation to climate change to be at least as important; moreover, they expected financial and technological assistance to their countries to carry out such tasks. Nevertheless, the overall focus of the debate was mainly on the extent of the emissions-related commitments of the industrialized countries, and this was reflected in the provisions of the legal instruments adopted in 1992, then in 1997 and 2012.
- Ultimately, the necessity of both scopes of action was accepted, and the relationship between the two was settled by the *Paris Agreement* as follows: "Parties recognize that the current need for adaptation is significant and that greater levels of mitigation can reduce the need for additional adaptation efforts" [UNFCCC/PA, 2015: 7.4.].

4.3.2. The evolution of cooperation: from skepticism to recognition of climate change as a common concern of mankind

The history of international environmental policymaking, including the common political wills for cooperation, the significance of the coordinated measures that were adopted, and the effectiveness of their implementation, has been rather 'uneven', i.e., more or less cyclically fluctuating, over the past half century. The same variability (volatile trends) has characterized climate-change-related cooperation. The following subperiods can be considered outstanding from this perspective: (i) the international conferences held in the first half of the 1970s, (ii) the 'upswing' in policy collaboration from the late 1980s for about a decade, which led, among other things, to the adoption of the climate change convention and other major environmental agreements, as well as a holistic sustainable development agenda, and finally, (iii) the subperiod from the beginning of the previous decade that resulted in a new sustainable development agenda with specific goals and a new climate policy agreement by 2015, as well (although this 'momentum' seems to have ceased for some time now). These stages were followed, at least at the level of international 'high politics', by a kind of apathy, associated with, for various reasons, much more moderate determination to fulfill even previously agreed goals and tasks.

More reliable scientific knowledge is needed. In the case of climate change, too, it was first necessary to agree on facilitating extensive and more thorough studies before formulating 'climate protection' policies and measures.

- One of the goals of the conferences held in 1970 and 1971 with the support of M.I.T. (USA) and the Royal Swedish Academy of Sciences was to encourage and lay the scientific foundation for

decisions to be made at the UN meeting planned for 1972 on supporting further climate change research and already even on some risk-mitigation measures. The experts agreed on the possibility of inadvertent human-induced climate change and that its factors and consequences were not yet sufficiently clear [SMIC, 1971].

- At the 1972 UN meeting (UNCHE, Stockholm), only a few recommendations dealt with the climate change issue, primarily in terms of support for climate observations, analyses, and impact assessments [UNCHE, 1972: recommendations 57, 70, and 79]. One of these indirectly called for a precautionary approach without using this term: "It is recommended that Governments be mindful of activities in which there is an appreciable risk of effects on climate, and to this end: (a) Carefully evaluate the likelihood and magnitude of climatic effects and disseminate their findings to the maximum extent feasible before embarking on such activities" (Recommendation 70). The significance of the adopted action plan was 'nuanced' by the fact that this UN conference was boycotted by several Eastern European countries (albeit not due to political conflict directly related to its theme). After the tension subsided, at the 1975 pan-European conference (Helsinki), representatives of the latter countries contributed to the adoption of the outcome document (Final Act) that referred to the former UN meeting held in Stockholm and the cooperation in climate change research [CSCE, 1975].[683]
- The scientific community investigating the 'climate problem' progressed on its own path after 1975. References were made above to the main developments, such as the WMO statement (1976), the Gibbs report (1976), the World Climate Conference (1979), and the international expert meetings held in Villach (1980, 1985). However, climate policy cooperation stalled because the representatives of 'high politics' had very different priorities after the years of 'détente'. The political climate became much more unfavorable during the period after the mid-1970s until about 1985 – which is called by some historians the time of the second or little Cold War – when shared political concern about increasing environmental problems receded into the background. This was echoed in the assessment of the political significance of the 1979 World Climate Conference (as opposed to the scientific one cited above): "From a scientific point of view it was a complete success. The same could not be said of the press coverage and political impact of the conference." [Czelnai, 2006] Daniel Bodansky shared this opinion and extended it to the 1985 Villach conference [Bodansky, 2001].[684]

Changes in world politics since the mid-1980s again led to a refocusing of attention on human-induced globalizing environmental problems, such as the then-discovered threat to the ozone layer, the global climate change hazard, or rapidly shrinking biological diversity. The 1986 Chernobyl nuclear disaster and the grave chemical contamination of the Rhine shook up European environmental cooperation in particular.

- In some countries, the extensive environmental issues – with transboundary or even global scale dangerous implications – were already being addressed at the highest political level. In recognition of this, the Norwegian Prime Minister (G.H. Brundtland) was invited to chair the World Commission on Environment and Development (WCED) established by a 1987 UN resolution, and then, together with the Canadian Prime Minister (B.M. Mulroney), they became the keynote speakers at the 1988 Toronto climate conference.
- In October 1987 and June 1988, hearings on climate change were held in the US Senate, where renowned researchers (J.E. Hansen, S. Manabe, V. Ramanathan) summarized the scientific knowledge gained so far on this topic. International cooperation in this field was strongly

[683] "Study of changes in climate, landscapes and ecological balances under the impact of both natural factors and human activities […]. The participating States […] will develop co-operation in the field of the environment in particular by taking into consideration the Stockholm Declaration on the Human Environment". (p. 29)

[684] "As late as 1979, efforts by the organizers of the (first) World Climate Conference to attract participation by policy makers proved unsuccessful, and even in 1985, when a major workshop on climate change was held in Villach (Austria), the U.S. government officials who participated went without specific instructions." (p. 24)

supported by the US leadership at the time, including the formation of the IPCC and the development of a climate protection agreement.

- In a speech given in the Bundestag in March 1987, the German Chancellor (H. Kohl) called climate change the most serious environmental problem. The German parliament's climate committee also began its activities that year.[685] In September 1988, the British Prime Minister (M. Thatcher) stressed in a lecture delivered to the Royal Society that climate change caused by human activities must be taken seriously. The Maltese Foreign Minister (V. Tabone, President of Malta from 1989) identified with this position to such an extent that, on behalf of his country, he became the initiator and proponent of the first UN resolution on climate change in 1988.[686]

Some previous 'models' and the emerging recommendations for international climate action. The breakthrough in the formulation of coordinated climate policies was facilitated by several international events in 1987 and 1988, the impact of which is generally instructive in terms of how identification with a multifaceted, global problem may reach the arena of international politics from the confines of science.

- Two significant environmental agreements (as important precedents) that were adopted immediately before the more concrete consideration of options for international policy responses to climate change are worth mentioning: the *Montreal Protocol* for the protection of the ozone layer was approved in 1987 and the (first) 'sulfur protocol' to the *Convention on Long-Range Transboundary Air Pollution* that entered into force in the same year. Their essence was the same: reducing atmospheric emissions from human activities that threaten the environment. It should be added that in the case of environmental acidification and ozone layer depletion, scientific certainty about the cause-and-effect relationships was already much greater than with anthropogenic climate change.
- We have mentioned above the June 1988 Toronto conference on climate change, attended by researchers and politicians, at which participants from around forty countries reemphasized the need for an agreement to reduce carbon dioxide emissions. Similarly, this was pointed out in the report compiled by the World Commission on Environment and Development in 1987. The IPCC, which had been active since November 1988, had the fundamental aim of facilitating political decisions by assessing and summarizing scientific knowledge about climate change and its anthropogenic aspects.
- All of this was not sufficient to achieve the global political consensus necessary to develop a treaty on climate change. Although the IPCC was established as an *intergovernmental* body, this in itself did not prove the existence of a broad political commitment to climate protection. Its first president, Bert Bolin, explained the situation this way: only a few countries actively supported the establishment of this body, but in fact, climate change became a topic of global political cooperation when the UN General Assembly adopted its first resolution on the matter [Bolin, 2007].[687]

Global political acceptance of the anthropogenic climate change hazard. The agenda items of the regular session of the UN, which began in September 1988, included the consideration of sustainable development and climate change.

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[685] Bundestag: Klima-Enquête-Kommission.

[686] Malta's commitment to this issue was demonstrated, for example, by its organizing an international expert meeting on climate change in 1990, at the opening of which President Vincent Tabone delivered a speech on the importance of climate policy cooperation. The author of this book was one of the participants invited to this event. (Workshop on Assessing Winners and Losers in the Context of Global Warming. Malta, 18-21 June 1990).

[687] "Merely 28 countries responded to the call for the meeting in Geneva in November 1988 in order to form a panel on climate change […]. The climate issue was still not high on the political agenda. […] The fact that the issue of climate change had been brought to the attention of the UN General Assembly implicitly meant recognition of the importance of the climate change issue and also of the IPCC itself." (pp. 63, 67)

- Malta requested that the General Assembly discuss the climate protection proposal it had prepared[688] and then put on the agenda the draft resolution submitted in October 1988 that specified it. The final version of the latter was compiled taking into account the comments and suggestions made during the general debate. It is instructive to highlight the reasons for some of the amendments to the text: (i) there was no consensus on the urgency and extent of climate-change-related interventions, (ii) according to representatives of developing countries, not only environmental impacts but also potential socioeconomic ones should be assessed and tackled, (iii) opinions differed on the need for a separate climate protection agreement, because many represented the view that the existing legal instrument(s) could be supplemented with the necessary provisions.[689]
- On 6 December 1988, the General Assembly adopted a resolution entitled '*Protection of the global climate for present and future generations of mankind*'. This expressed the growing concern about climate change caused by increasing emissions of greenhouse gases and, among other things, stressed the need to prevent detrimental effects on the climate and to determine the necessary actions as soon as possible [UN, 1988].[690]
- Therefore, 1988 was a major 'turning point' in the history of international climate policy advancement. The above-mentioned resolution proposed by the Maltese delegation (based on the recommendations of the Toronto conference) and adopted by the UN General Assembly called not only for the formulation of appropriate international response measures, but also turned to the IPCC, established that year, to specify and substantiate the latter.[691]

4.3.3. International agreements: goals, regulations, and compromises

The possible goals and details of a comprehensive climate protection agreement were discussed in international conferences held in 1989 and 1990 with the participation of researchers and politicians: in March 1989 in The Hague, in November 1989 in Nordwijk, in May 1990 in Bergen, and then in November 1990 at the Second World Climate Conference in Geneva [Jäger & Ferguson, 1991].

The legal framework on climate change: a framework for climate policy cooperation. At the end of 1989, the UN General Assembly adopted another resolution on the need for such a convention and the commencement of its negotiations [UN, 1989].[692]

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[688] "Conservation of climate as part of the common heritage of mankind".

[689] Text excerpts from the draft (*d*) and the final version (*f*) with highlights, indicating some essential compromises: (**i**) regarding urgency and extent: (*d*) *urgent* action *must be* taken; (*f*) *necessary* and *timely* action should be taken; (*d*) – (*f*) *realistic* response strategies; (**ii**) about the impacts: (*d*) potential impact of climate change; (*f*) potential *environmental and socio-economic impact* of climate change; (**iii**) concerning the relevant legal instrument: (*d*) a future international convention on climate; (*f*) a *possible* future international convention on climate.

[690] The General Assembly requests the Secretary-General of the WMO and the Executive Director of the UNEP, through the IPCC: "immediately to initiate action leading, as soon as possible, to a comprehensive review and recommendations with respect to: […] (c) Possible response strategies to delay, limit or mitigate the impact of adverse climate change; (d) The identification and possible strengthening of relevant existing international legal instruments having a bearing on climate; (e) Elements for inclusion in a possible future international convention on climate".

[691] The 1987 WCED report, in addition to the development of a climate protection convention, also proposed a "convention on the conservation of species". The negotiations on the latter began under the auspices of UNEP in November 1988 and were also completed by 1992 [Nechay & Faragó, 1992]. From 1988 onwards, the preparation for the 'Rio summit' and the development of the two global conventions proved to be not only complementary but also mutually reinforcing political cooperation processes.

[692] The General Assembly "recommends that such negotiations begin as soon as possible after the adoption of the interim report of the IPCC".

- The IPCC's first report was completed by August 1990, and in light of this, a decision was made at the end of 1990 on the mandate of the Intergovernmental Negotiating Committee (INC) elaborating the convention [IPCC, 1990; UN, 1990[693]]. Negotiations began in February 1991, and the text of this legal instrument was finalized on May 9, 1992 [UNFCCC, 1992; Faragó & Pálvölgyi, 1992].[694] The *UN Framework Convention on Climate Change* entered into force within two years and all UN Member States became Parties to it. The most general formulation of what needs to be achieved as soon as possible and why, has remained completely valid ever since (Article 2): "The ultimate objective of this Convention […], stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

- The most important provisions were directly linked to this objective. All Parties became obliged to address anthropogenic greenhouse gas emissions and their removal from the atmosphere, as well as to prepare for the impacts of climate change. For developed countries – due to their greater historical responsibility for this global hazard – the much more specific commitments included the adoption of policies and measures aimed at the limitation of such emissions ("the return by the end of the present decade to earlier levels of anthropogenic emissions") and the provision of financial and technological support to developing countries to fulfill their obligations. (Several Central and Eastern European countries with 'economies in transition' – including Hungary – also assumed emission control obligations, sometimes with a reference level different from the default one of 1990. In the following, when reference is made to the 'group of developed countries', this includes those countries of the CEE region that undertook similar obligations in terms of mitigation and adaptation measures.[695])

Compromises: groups of countries with differentiated responsibilities, dissimilar situations and differing interests. General acknowledgement of the threat of anthropogenic climate change affecting all societies in one way or another was a fundamental condition for the establishment of the global climate agreement, but beyond this, the text of this legal instrument could only be finalized through major compromises reached by the negotiating delegations on a number of critical issues.

- Beyond the adoption of the objective of preventing "dangerous anthropogenic interference with the climate system", no concrete targets were defined for the global control of greenhouse gas emissions. The main reasons for this were the remaining scientific uncertainty and the 'inertia' of the socioeconomic development process, which was closely linked, among other things, to the large-scale use of fossil fuels.

- The developed countries were therefore ready to acknowledge their greater responsibility and take the lead in combating this global problem. However, the objective of the convention was obviously unattainable with only common general but unspecific emission control commitments and some concrete but temporary emission stabilization ones applicable exclusively to developed countries. Consequently, it was accepted that the adequacy of latter commitments would be reviewed after the entry into force of the convention (UNFCCC, 4.2.d), but this review did not happen because the Parties could not agree on the interpretation of that provision.

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[693] "Decides to establish a single intergovernmental negotiating process under the auspices of the General Assembly […] for the preparation by an Intergovernmental Negotiating Committee of an effective framework convention on climate change"; "Considers that the negotiations […] should be completed prior to the United Nations Conference on Environment and Development in June 1992 and opened for signature during the Conference".

[694] The author of this book represented Hungary at the 1991/1992 negotiations (Geneva, New York), including the May 1992 session where the text was finalized (at the cost of 'difficult' compromises).

[695] These CEE countries were provided with some 'flexibilities' concerning the implementation of their commitments in view of their specific situation; their special status was indicated in Annex I of the Convention (1992), Annex B of the Kyoto Protocol (1997) and also in the Annex I of its Doha Amendment (2012).

- The *Convention* indicated that the specific situation of several groups of countries must be taken into account in the implementation of respective commitments, including (i) developing countries that were particularly vulnerable to the adverse effects of climate change, (ii) countries with 'economies in transition', and (iii) developed and developing countries whose economies were highly dependent on fossil fuels (their production, consumption, etc.) [UNFCCC, 1992: 4.6., 4.8., 4.10.].

Growing knowledge of causes, effects, intervention options, and changing political interests/priorities. During the past decades since the *Convention* was adopted, much more thorough and accurate knowledge has been obtained not only about the causes and consequences of the currently unfolding climate change, but also about the possibilities for mitigating this process and adapting to its seemingly inevitable effects.

- The assessment reports of the IPCC increasingly provided more robust and detailed recommendations for controlling greenhouse gas emissions [Faragó, 2016a: Table 2]. According to these, global emissions should decline within a few decades [IPCC, 1995; IPCC, 2001], be reduced by at least half by 2050 [IPCC, 2007] and they should not increase in any region from 2020 onward [IPCC, 2014]. The global emissions reduction targets published in the 2021 report called for even faster and deeper interventions [IPCC/WG-I, 2021].
- The dialogue between climate science and climate policy representatives became continuous: its international institutional frameworks were created primarily by the IPCC, its founders, i.e., UNEP and WMO, and the cooperation of these organizations with the relevant convention bodies. (This was also the mandate of the Joint Working Group of representatives of the IPCC and the scientific advisory body established by the *Convention*.)[696]
- Meanwhile, the situation and interests of countries changed in a way that has strongly affected their participation in this international cooperation, the positions they have represented in it, and their national climate policies as well. Here are some examples of this. (i) Successive US leaders, representing different political priorities, have had very different views on this problematic and the importance of international climate policymaking, and, depending on this, on their country's participation in the related global intergovernmental collaboration (see below). (ii) The EU was increasingly at the forefront of these negotiations, the implementation of the agreements and also in terms of its own commitments from the beginning [Faragó, 2018a], but in order to succeed in this, rather 'asymmetrical' agreements had to be reached between the EU Member States because of their differing situations (in terms of 'burden sharing' or, as later called with more positive connotations, 'effort sharing'). (iii) Moreover, it had a major impact on positions and arguments regarding the further development of global climate policies was the fact that in around 2010 the aggregate carbon dioxide emissions of developing countries reached those of developed countries (and the annual emissions of the PRC caught up with and then increasingly exceeded those of the US).

New agreements, but without resolving the dilemma between the largest GHG-emitting developed and developing countries. As with other international legal instruments, the provisions of the *UN Framework Convention on Climate Change* have been tightened and supplemented in light of new data, scientific knowledge, and technical possibilities.

- Following the entry into force of the *Convention*, negotiations initiated at the first meeting of the Parties under the 'Berlin Mandate' (1995) resulted in the *Kyoto Protocol* being completed by the end of 1997. Developed countries committed to an average 5% emission reduction by 2012 [UNFCCC/KP, 1997; Faragó et al., 1998; Faragó, 2011]. This protocol only entered into force several

[696] Joint Working Group (JWG) of SBSTA (Subsidiary Body for Scientific and Technological Advice) and the IPCC: the author of this book was elected the first Chair of that body and, in that capacity, he and Bert Bolin, the distinguished first Chair of the IPCC, became Co-Chairs of the JWG (1995-1997).

years later, on February 16, 2005. The USA did not ratify it, and the Russian side did so only at the end of 2004: if both had rejected accession, the entry into force of this legal instrument would have become impossible [UNFCCC/KP, 1997: Art. 25.1].[697]

- Seeing that global emissions were still barely slowing down, a decade later, at the end of the negotiation round initiated by the 2007 session of the Parties (as part of the Bali Action Plan), the *Doha Amendment* to the *Kyoto Protocol* (DA) was adopted in 2012 with new emission reduction commitments for developed countries to be met by 2020 [UNFCCC/DA, 2012]. This legal instrument was also based on the 'common but differentiated responsibilities' approach, i.e., it tightened the obligations of developed countries and recognized the different situations of developing countries (although the differences in development and resulting environmental burden among certain groups of the latter had increased significantly). Several negotiating parties claimed that developing countries with rapid economic and greenhouse gas emission growth should also undertake to limit/mitigate increases in these emissions. When this did not happen, several 'large-emitting' developed countries[698] were unwilling to participate in the DA, and this was one of the key reasons why this legal instrument entered into force only on 31 December 2020, i.e., at the very end of the year that was the target date for respective emission reductions under this amendment. (It is worth noting that the emissions-related commitment undertaken by the EU Member States collectively was a 20% reduction compared to 1990 levels to be fulfilled by 2020.)

- The above 'developed-developing world conflict' could have been resolved if all Parties had made commitments that took into account, primarily, their varying shares of (historical and current) responsibility in terms of overall global emissions. This was achieved to some extent with the 2015 *Paris Agreement*, but (i) the general distinction between the requirements applicable to developed and developing countries remained,[699] (ii) at the cost of the fact that this agreement did not define quantified targets for any group of countries. Instead, the 'ultimate' objective set out in the *Convention* was specified through determining limits for the increase in global average surface temperature: "holding the increase in the global average temperature to well below 2 C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 C above pre-industrial levels" [UNFCCC/PA, 2015: 2.1.(a); Faragó, 2016b]. In subsequent rounds of climate negotiations, the primary intention was to facilitate the implementation of the provisions of the aforementioned agreement. Particularly noteworthy in this regard was the call first for coal only, and then for a general reduction in the use of fossil fuels in energy systems (consequently leading to the decrease of the resulting carbon

[697] "This Protocol shall enter into force on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55 per cent of the total carbon dioxide emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification". (The latter condition would have guaranteed the future participation of the two above-mentioned countries, i.e., Russia and the USA, in the 'emission trading' mechanism introduced by Article 17).

[698] Canada did not become a Party to the Doha Amendment (and had already withdrawn from the Kyoto Protocol before 2012). Japan and Russia did not accept the Amendment but remained Parties to the original Kyoto Protocol. New Zealand accepted the Amendment, but without committing to any specific emission reduction targets. The USA is not a Party to either the Kyoto Protocol or the Doha Amendment.

[699] "Developed country Parties should continue taking the lead by undertaking economy-wide absolute emission reduction targets. Developing country Parties should continue enhancing their mitigation efforts, and are encouraged to move over time towards economy-wide emission reduction or limitation targets". (4.4.)

dioxide emissions into the atmosphere), although no specific means were identified for fulfilling these aims [UNFCCC/GCP, 2021; Faragó, 2022b; UNFCCC/GST, 2023].[700]

Multilateral environmental diplomacy. In international negotiation processes burdened with a diversity of differences in situations and interests, reaching consensus on an outcome document also depends on the ability of the negotiating parties and those facilitating the negotiations to identify compromises acceptable to all delegations, or at least formulations that everyone can interpret according to their own interests. These compromises may indicate, but often – precisely because of their ambiguity – do not prove the effectiveness of multilateral diplomacy in solving a commonly recognized problem. Climate policy negotiations have always been characterized by a number of such 'bridging' compromises.[701] In illustration of this, here are some 'notable' examples of the latter that enabled the finalization of certain agreements, decisions, and provisions.

- The passage in the *Convention* (1992) referring to emission control commitments by developed countries did *not* actually stipulate clear obligations in a legal sense [UNFCCC, 1992: 4.2.(a)].[702] (Only its rather 'complicated' wording made it possible to bridge the different positions of developed countries regarding the timeliness, extent of emission regulations, and their legally binding/non-binding nature.)
- In order for the countries with 'economies in transition' that had fallen into a deep recession to join the group of developed countries ready to control their emissions, they were allowed in the implementation of their commitments "a certain degree of flexibility […] in order to enhance the ability of these Parties to address climate change" [UNFCCC, 1992: 4.5.; Faragó, 2012]. (This compromise was essential because at that time, it was not possible to foresee how the economic structure and environmentally harmful emissions of these countries would change in the near future.)
- In the almost final moments before the adoption of the *Paris Agreement*, a single exchange of words allowed the US to contribute to the consensus [UNFCCC/PA, 2015: 4.4.].[703] In addition, this agreement is not a 'protocol' for a reason, unlike the *Kyoto Protocol*, which only imposed quantified emission control tasks on developed countries; therefore, the *Paris Agreement* may be

[700] The Conference of the Parties "Calls upon Parties to accelerate […] efforts towards the *phasedown of unabated coal power* and phase-out of inefficient fossil fuel subsidies …" [UNFCCC/GCP, 2021: par. 20]. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement calls on Parties to contribute to the following global efforts "(a) Tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvements by 2030; (b) Accelerating efforts towards the phase-down of unabated coal power; (c) Accelerating efforts globally towards net zero emission energy systems, utilizing zero- and low-carbon fuels well before or by around mid-century; (d) *Transitioning away from fossil fuels in energy systems*, in a just, orderly and equitable manner, accelerating action in this critical decade, so as to achieve net zero by 2050 in keeping with the science; …" [UNFCCC/GST, 2023: par. 28].

[701] The author of this book was Hungary's principal climate policy negotiator between 1991 and 2010 and contributed to the achievement of several such compromises; he was also present as an observer at the sessions of the Conference of the Parties in 2013 (Warsaw) and 2015 (Paris) and published assessments on these events and their outcomes [Faragó, 2014; Faragó, 2016b] and likewise on the majority of such previous rounds of negotiations.

[702] "[P]olicies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions […], recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions […] would contribute to such modification".

[703] In the (almost final) draft it was presented as follows: "Developed country Parties *shall* continue taking the lead by undertaking economy-wide absolute emission reduction targets"; whilst a single word was changed in the final and adopted version: "Developed country Parties *should* continue taking the lead".

considered 'merely' an implementation instrument of the original *Convention*, to which the USA was a Party.[704]

* * *

The conclusion of international climate policy agreements was a significant achievement from a general political and diplomatic perspective, primarily because a consensus was reached on a global problem that represents an increasingly serious concern for all nations and almost every key economic sector (via their contribution to and also bearing the effects of this hazardous process) – although very differently for individual societies and economies. However, based on the actual content and obligations contained therein, their effectiveness can only be assessed with serious reservations, which we will discuss below.

4.4. ARE THE CLIMATE AGREEMENTS AND THEIR IMPLEMENTATION EFFECTIVE?

There are currently four global legal instruments dedicated to climate protection: the 1992 *Framework Convention*, its *Kyoto Protocol* (1997), the *Doha Amendment* to the latter (2012), and the *Paris Agreement* (2015). This is a more or less clear indication that the threat of anthropogenic climate change has become a major issue for international political cooperation. However, the existence of these instruments alone does not imply that the actions taken by the international community so far are adequately aligned with the growing scientific understanding of this hazard or sufficient to effectively address it. In this regard, any complex evaluation should cover the legal and environmental effectiveness of these agreements by taking into account the general and specific goals, obligations, and other key provisions, as well as their implementation.

4.4.1. The provisions of the agreements and the extent of their (f)actual fulfillment

> By the time the climate change convention was initiated, developed, and finalized (1988-1992), scientific research into human-induced anthropogenic climate change was at a fairly advanced stage. According to the first assessment report of the Intergovernmental Panel on Climate Change, this process could potentially have substantial impacts, but it was not yet possible to clearly demonstrate, for instance, the increase in global surface temperature beyond its natural variability or to identify any other presumed implications (such as sea level rise) or estimate potential further ones [IPCC, 1990].[705]

The Convention and its supplementing legal instruments on climate change. *The UN Framework Convention on Climate Change* – citing the knowledge gaps of the time (i.e., the remaining scientific uncertainties) about this global process, and thus in the spirit of precaution – included only some initial policies and measures. Moreover, it stated that further steps should be considered depending

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[704] Thus, the deposit of the relevant instrument signed by the then US President (B. Obama) was sufficient for the USA to become a Party to this *Agreement* on September 3, 2016 (while, in order to ratify a new *protocol*, Congressional and Senate authorization would be required). As is known: based on the decision of the next president (D. Trump), the USA withdrew from this agreement, but on the initiative of the next president (J. Biden), they joined again the group of the Parties. Afterwards, one of the first actions of the returning president (D. Trump) in 2025 was to withdraw repeatedly from the *Paris Agreement*. Meanwhile, the USA has not left the original 1992 *UN Framework Convention on Climate Change* before or since.

[705] "There is concern that human activities may be inadvertently changing the climate of the globe […]. Global mean surface air temperature has increased by 0.3°C to 0.6°C over the last 100 years […]. The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability" (IPCC, 1992; WG-I/SPM).

on the results of ongoing observations and research [UNFCCC, 1992].[706] Their necessity soon became apparent.

- Global greenhouse gas emissions were increasing rapidly, and subsequent IPCC reports presented climate trends more accurately, along with the projections (scenarios) derived by means of improved numerical models and more detailed and substantiated recommendations for actions. Taking these into account, in the 1997 and 2012 regulatory instruments – the *Kyoto Protocol* and its *Doha Amendment* – the majority of developed countries already committed to some emission reductions (on both occasions for a period of about a decade), but overall, the commitments fell short of fulfilling the aforementioned science-based recommendations. Besides financial and technological assistance, the climate mitigation policies of developing countries could be directly promoted by the introduction of a special mechanism[707] that allowed developed countries to finance investments in their countries (if and where relevant at all) that would reduce emissions to some extent, e.g., in the energy sector.
- The fifth comprehensive report of the IPCC, finalized in 2014, and the UNEP 'gap-assessment' publication issued in the same year, demonstrated the inadequacy of international climate policies to date and the worsening of the 'climate situation'. According to the former: "Without additional efforts to reduce GHG emissions beyond those in place today, emissions growth is expected to persist, driven by growth in global population and economic activities despite improvements in energy supply and end-use technologies" [IPCC/WG-III, 2014: p. 49]. The UNEP report confirmed this and stated the need for further steps: "It is clear that global emissions are not expected to peak unless additional emission reduction policies are introduced." [UNEP/EGR, 2014: p. 20] These assessments also fostered the creation of a truly inclusive and wide-ranging climate treaty in 2015. The *Paris Agreement*, to be implemented from 2020, introduced detailed procedures for all Parties yet left it to each of them to voluntarily decide to what extent and how to contribute to achieving the common goals.

It proved challenging to agree on specific and sufficiently ambitious climate policy goals and related obligations because achieving substantial greenhouse gas emission reductions in the sectors most concerned and transitioning to appropriate – and at the same time broadly sustainable – production and consumption patterns seemed very difficult.

- The 1992 *Convention* did indeed provide a general framework for tackling the climate change hazard and further negotiations, but it was and remained doubtful that the more-or-less specific targets set out in that and the three subsequent supplementary instruments and the application of the diverse procedures and tools introduced therein would bring the international community significantly closer to achieving the 'ultimate' objective [UNFCCC, 1992: Art. 2].
- While the *Convention* became 'universal' (essentially all UN Member States became Parties to it), the fate of the *Kyoto Protocol* (1997) and its *Doha Amendment* (2012) was very different. The former's target date for the fulfillment of developed countries' emission control/reduction commitments was 2012, while this legal instrument only entered into force halfway through this period, i.e., in 2005. Meeting the specific criteria required for its entry into force was slow because – in addition to the fact that the USA did not become a Party ab ovo and the Russian Federation only ratified it at the end of 2004 –, numerous other countries also waited a long time to take this step. To top it all off, Canada withdrew from the *Protocol* just before the aforementioned date of 2012 (because it was deemed that the country would not be able to achieve the 6% emission reductions it had committed to). In the case of the *Doha Amendment*, only three-quarters of UN Member States became Parties to it, and many of them, including several EU Member States, did

[706] "The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects" (3.3). Promote research: "intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding the causes, effects, magnitude and timing of climate change and the economic and social consequences of various response strategies" (4.1.g).

[707] The Clean Development Mechanism was introduced by the Kyoto Protocol (Art. 12).

so only after the *Paris Agreement* was adopted in 2015. Of the Parties to the latter, only a few developing countries were left out, and as mentioned above, the USA sometimes accepted and sometimes withdrew from this agreement, while this legal instrument did not set any specific time-bound emission reduction targets or other particularly demanding requirements, even for developed countries. Besides the 'sufficiency' (level of ambition), the doubts about the effectiveness of all four climate treaties thus far were further compounded by the fact that numerous developing countries and some developed countries did not prepare and implement programs, action plans, and/or national legislation consistent with their commitments to meet the goals and obligations contained therein. Beyond all this, the fundamental question regarding the environmental (or ecological) effectiveness of these instruments was this: How have human activities that trigger this global perilous process changed together with the resulting pressures on the climate system and their injurious influences?

4.4.2. What about the coherence of climate science and climate policy?

The relationship between science and politics: science-based recommendations and policy commitments. The achievements of scientific research regarding anthropogenic climate change have provided the basis for climate policy responses and commitments, while they were also influenced by a number of socioeconomic, political, and technological factors.

- The early phase of scientific cooperation on this matter was marked by events such as the 1971 climate conference held in Stockholm, the climate research sub-program initiated in 1974 as part of the Global Atmospheric Research Programme (GARP), the Geneva conference that launched the World Climate Programme in 1979 and the international expert meetings held in the second half of the 1980s. Being catalyzed by these developments, the climate policy recommendations by the time of the 1972 UN Conference on the Human Environment aimed (only) to further promote monitoring and research activities. In the 1980s, options for some concrete response policies were already being considered at various forums. Then, a shift to a better understanding of the hazardousness of the ongoing climate system changes and the urging of relevant decisions occurred, and the first IPCC report (1990) already stated the need for actions to address the increasing greenhouse gas emissions [IPCC, 1990].[708]
- The scientific community recommended, as a first step, to halt the growth of such emissions from developed countries as soon as possible, and this goal was included in the 1992 *Framework Convention*, but only by the end of that decade. Subsequently, in response to newer scientific advice on greater emission reductions, the 1997 *Protocol* and its 2012 *Amendment* stipulated that at least developed countries should make such commitments – albeit initially on a relatively modest scale and then somewhat more ambitiously. But their rates of reduction also fell significantly short of the levels suggested by the analysts mentioned above, while global emissions continued to go up [IPCC/WG-III, 2014; UNEP/EGR, 2014], and sink capacities

[708] "… recognition of the responsibility of all countries to make efforts at the national, regional, and global levels to limit or reduce greenhouse gas emissions and prevent activities that could adversely affect climate […] recognition of the need to develop strategies to absorb greenhouse gases, i.e., protect and increase greenhouse gas sinks" (WG-III, SPM: pp. lvii-lix].

decreased primarily due to expansive land use changes and deforestation [UNFF 2009[709]; UNFF, 2015[710]].

- This situation has thoroughly changed since the beginning of the 2010s because the objective of the 1992 *Convention* was expressed in much more concrete terms by determining critical threshold values for the average surface temperature rise that should not be exceeded. Based on this, the pace was derived at which the global (net) 'zeroing' of anthropogenic GHG emissions should be achieved. As a matter of fact, as early as 2007, the fourth report of the IPCC presented an assessment of the likely worsening impacts if global average temperatures continued to rise to about 1.5-2.5°C above pre-industrial levels [IPCC, 2007], and based on this, such temperature thresholds were included in the 2009 *Copenhagen Accord*. This was adopted by the majority of heads of delegations participating in that session of the climate negotiations, and it reads as follows: "2. We agree that deep cuts in global emissions are required according to science, […] so as to hold the increase in global temperature below 2 degrees Celsius […] 6. We recognize the crucial role of reducing emissions from deforestation and forest degradation and the need to enhance removals of greenhouse gas emissions by forests […] 12. We call for an assessment of the implementation of this *Accord* to be completed by 2015, including in light of the Convention's ultimate objective. This would include consideration of strengthening the long-term goal referencing various matters presented by the science, including in relation to temperature rises of 1.5 degrees Celsius." [UNFCCC, 2009] The IPCC's *Fifth Assessment Report* (2014) presented the global emission reduction scenarios that were in compliance with these critical temperature threshold values, which were taken into account for defining the (albeit much less precise) emission regulation provisions in the 2015 *Paris Agreement*.

The increasing science-policy gap? The most crucial question, as raised at the outset, is how effective (or at least how incrementally more effective) have international steps been in addressing the global climate change hazard in light of growing scientific certainty.[711]

- After the turn of the millennium, the scientific community proposed emission reductions that were of a far larger scale than those previously undertaken and achieved, primarily by developed countries but also at a global level. In light of newer observational data and more complete climate model outcomes, 'drastic' cuts in those emissions were recommended: "Scenarios that are likely to maintain warming at below 2°C are characterized by a 40% to 70% reduction in GHG emissions by 2050, relative to 2010 levels, […] scenarios that are more likely than not to limit warming to 1.5°C by 2100 […] are characterized by concentrations below 430 ppm CO_2-eq by 2100 and 2050 emission reduction between 70 and 95% below 2010." [IPCC/SYR, 2014: p. 39] The reason for the need for more robust efforts was also evident from the UNEP assessment issued just before the next round of climate policy negotiations to be held in Paris: "Over the past decades global GHG emissions have been increasing steadily, with small variations around a longer-term trend." [UNEP/EGR, 2015: Executive Summary, p. 2]
- In contrast, the related provisions of the 2015 *Paris Agreement* were worded much more cautiously, namely: "Article 2 (a) Holding the increase in the global average temperature to well

[709] The United Nations Forum on Forests "1. Decides (a) To encourage Member States to strengthen the implementation of sustainable forest management in addressing the challenges of forests in a changing environment, including climate change, loss of forest cover, forest degradation, desertification and biodiversity loss, in the context of sustainable development; […] 2. Also decides: (a) To underscore the urgency to address the threats and sustainable development challenges posed by climate change …"

[710] Ministerial declaration "4. We reaffirm our strong commitment to forests and the sustainable management of all types of forests. The sustainable management of all types of forests is vital to facilitate transformative change and address major challenges, such as […] climate change mitigation and adaptation […] 5. We are deeply concerned about the continued deforestation and degradation of forests in many regions and underscore the need to reverse this trend …"

[711] The author of this book has presented in detail the evolution of the global science-policy gap concerning the approach to the of anthropogenic climate change, starting from the 1980s and including the Paris Agreement [Faragó, 2016a; Faragó, 2018b].

below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels […] Article 4. 1. In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter […], so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century …" [UNFCCC/PA, 2015]. The 'balance' mentioned above refers to the goal of 'climate neutrality'; that is, that the remaining emissions are compensated (or offset) by enhancing the removal of such trace gases from the atmosphere. But even if this 'neutrality' is achieved, the human-induced 'climate problem' would continue for a lengthy period [IPCC/SYR, 2014[712]; Haszpra, 2016[713]].

- In line with the *Paris Agreement*, as mentioned, it was assumed that each Party to it would undertake 'voluntary' commitments as Nationally Determined Contributions (NDCs) to the global response to climate change. Such NDCs would then be updated successively to "represent a progression beyond the Party's then current nationally determined contribution and reflect its highest possible ambition" [UNFCCC/PA, 2015: Art. 3, Art. 4: 2., 3.]. Actually, two basic categories of such policies could be distinguished: those undertaken 'unconditionally' and 'conditional' ones. It turned out from the first synthesis report compiled in 2021 that the overwhelming majority of the Parties submitted such NDCs, but even their presumed complete implementation would still lead to a further considerable increase in global emissions[714] and extend their already lengthy tendency to rise (after the temporary downturn in 2020) [IEA, 2022; UNEP/EGR, 2022]. So, since the early 1990s, a considerable difference has emerged and remains between scientific recommendations for climate protection interventions on the one hand and climate policy responses and commitments at the international level on the other.

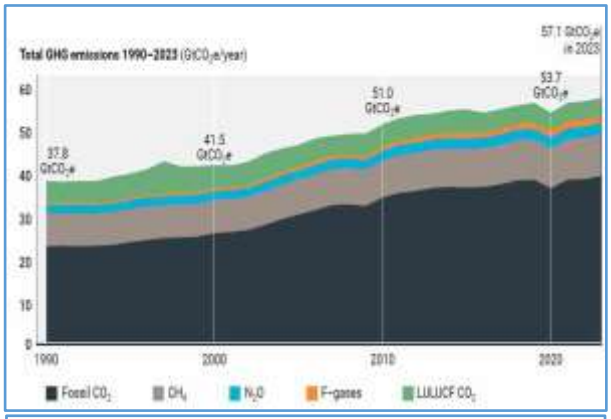

Figure 5 Anthropogenic emissions of GHGs, 1990-2023 ($GtCO_2e$). [UNEP/EGR, 2024]

- These problems have been even more pronounced at the global level in terms of the implementation of the commitments. The latest IPCC assessment report and the *Global Stocktake* approved at the 2023 session of the Parties to the *Paris Agreement* highlighted both these gaps, namely, the 'science-policy gap' and the 'implementation gap' and urged increased commitments and actions: (i) "Without urgent, effective, and equitable mitigation and adaptation actions, climate change increasingly threatens ecosystems, biodiversity, and the livelihoods, health and wellbeing of current and future generations" [IPCC/SYR, 2023: A.4.3]; (ii) "(24.) Notes with significant concern that, despite progress, global greenhouse gas emissions trajectories are not yet in line with the Paris Agreement temperature goal, and that there is a rapidly narrowing window for raising ambition and implementing existing commitments in order to achieve it; (37.) [R]equests Parties that have not yet done so to revisit and strengthen the 2030 targets in their nationally determined contributions as necessary to align with the Paris Agreement temperature

[712] "Many aspects of climate change and its impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases." (p. 30)

[713] "However, we must be aware that if human emissions were to cease completely, the biosphere, which absorbs about a quarter of the current anthropogenic CO_2 emissions, would reach equilibrium with the atmosphere within a few decades, so it would no longer function as a net sink, while the oceans would need a few thousand years to do so, with a gradually weakening capacity. However, about a tenth of the excess CO_2 released into the atmosphere would still be in the atmosphere ten thousand years later, exerting its warming effect." (p. 1453)

[714] "The total global GHG emission level in 2030, taking into account implementation of all the latest NDCs, is expected to be 15.9 per cent above the 2010 level." (UNFCCC/PA/CMA/2021/8/Rev.1, par. 13)

goal by the end of 2024, taking into account different national circumstances; (42.) Urges Parties that have not yet done so and invites all other Parties to communicate or revise, by the sixth session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (Nov. 2024), their long-term low greenhouse gas emission development strategies […] towards just transitions to net zero emissions by or around mid-century, taking into account different national circumstances" [UNFCCC/GST, 2023: 1/CMA.5 Outcome of the first global stocktake].

- The changes are clearly illustrated by the fact that, since 1990, global net GHG emissions increased by 35% by 2010 and by 51% by 2023 (Figure 5). [UNEP/EGR, 2024: p. 5] The atmospheric content of greenhouse gases continued to grow rapidly: "The latest analysis of observations from the WMO Global Atmosphere Watch (GAW) in situ observational network shows that the globally averaged surface concentrations for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) reached new highs in 2023, with CO_2 at 420.0±0.1 ppm, CH_4 at 1934±2 ppb and N_2O at 336.9±0.1 ppb. These values constitute, respectively, increases of 151%, 265%, and 125% relative to pre-industrial (before 1750) levels." [WMO/GGB, 2024]

- The risk of this global process and its adverse impacts has, therefore, increased further instead of being significantly reduced. Current NDCs are estimated to at least lead to a peak (ceiling) in global emissions by 2030 and a continuing not too steep downward trend thereafter, but compliance with the key expectations of the *Paris Agreement* (defined in terms of critical temperature thresholds) would require much more than this (Figure 6) [UNEP/EGR, 2024].

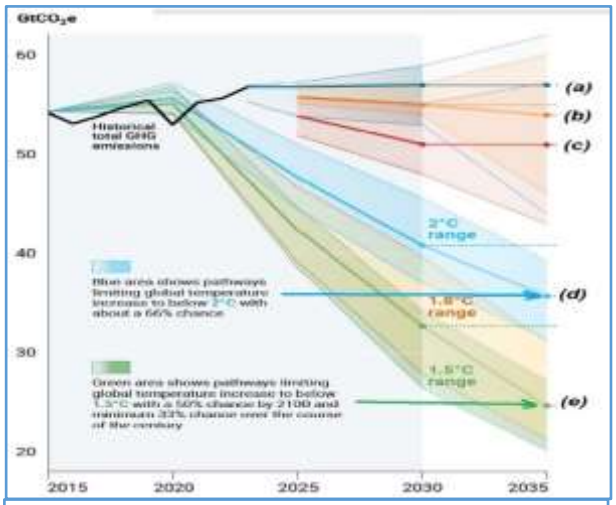

Figure 6 Scenarios of global GHG emission levels in 2035 dependent on current national policies and those derived from NDCs to be compared to global emission levels consistent with 2°C and 1.5°C (median estimates): *(a)* if current policies continued GHG=57 $GtCO_2e$, *(b)* if unconditional NDCs continued GHG=54 $GtCO_2e$, *(c)* if conditional NDCs continued GHG=51 $GtCO_2e$, *(d)* the level consistent with 2°C is 36 $GtCO_2e$, (e) the level consistent with 1.5°C is 25 $GtCO_2e$ [UNEP/EGR, 2024]

Adaptation and finance. The *Paris Agreement* identified two other key areas: besides reducing the risk of climate change, preparing for adaptation to its adverse effects, and ensuring sufficient financial resources to carry out the relevant tasks [UNFCCC/PA, 2015: par. 2].

- For a long time, the issue of adaptation primarily concerned the developing countries, but the *Agreement* brought about a shift in this area as well. In addition to defining a global adaptation goal, each Party was also required to develop and implement a national adaptation plan.[715] Comprehensive assessments have also been made of the status of the implementation of these obligations. While they indicate that some progress has been made, in many cases, there are serious problems with the 'quality' of national plans, including the fact that a large number of developing countries do not even have sufficient resources to elaborate one. The 'implementation gap' is also apparent: "Progress in adaptation implementation is slow and marred with problems. Countries need to ramp up their ambitions to prepare for increasing climate risks." [UNEP/AGR, 2024: p. xiii] The Parties to the *Paris Agreement*, therefore, adopted specific proposals to address these issues with a deadline of 2030.[716]

[715] "Article 7: 1. Parties hereby establish the global goal on adaptation of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change […] 9. Each Party shall, as appropriate, engage in adaptation planning processes and the implementation of actions, including the development or enhancement of relevant plans, policies and/or contributions, which may include: (a) The implementation of adaptation actions, undertakings and/or efforts; (b) The process to formulate and implement national adaptation plans; …".

[716] B. Adaptation: par. 63-65 [UNFCCC/GST, 2023].

- A particularly 'sensitive' component of the financing issue is facilitating the fulfillment of climate policy commitments by developing countries. This has also been on the agenda since the adoption of the 1992 *Convention*, and several financial funds have been established to facilitate its implementation, starting with the Global Environment Facility (GEF) and, among other mechanisms, the Green Climate Fund (GCF) established in 2009. Also, with regard to the 'differentiated responsibilities', it was primarily the developed countries that provided these resources, as also confirmed by the *Paris Agreement*.[717] In addition to delineating the scope of supported activities and the various rules governing the operation of these funding mechanisms, the most challenging aspect was always reaching a consensus on the overall amount of resources available for various projects. Recently, a critical assessment was provided on this matter in the framework of the *Global Stocktake* [UNFCCC/GST, 2023: C.1. Finance]. This may have partly contributed to the finalization and adoption of a 'deal' in 2024 entitled 'New collective quantified goal on climate finance', although improving effectiveness remained a challenge: "The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, […] 24. Calls on multilateral climate funds, including the operating entities of the Financial Mechanism, the Adaptation Fund, the Least Developed Countries Fund, and the Special Climate Change Fund, to strengthen their efforts to enhance access and promote effectiveness …" [UNFCCC, 2024]. (Apparently, this also applies to the two other financing mechanisms, the GEF and the GCF, which 'serve' entirely the *Convention* and not only the *Paris Agreement*.)

4.5. CONCLUSIONS AND LESSONS LEARNED

CLIMATE CHANGE: SCIENTIFIC INVESTIGATION OF THE CONSEQUENCES OF HUMAN ACTIVITIES AND THE DEVELOPMENT OF INTERNATIONAL CLIMATE POLICY

> "How can science be most useful to society when evidence is incomplete or ambiguous, the subjective judgments of experts about the likelihood of outcomes vary, and policymakers seek guidance and justification for courses of action that could cause significant environmental and societal changes?"
>
> *Stephen H. Schneider & Kristin Kuntz-Duriseti, 2002*[718]

Based on the examination of global climate-modifying human activities and their implications, as well as the development of international climate policy to date, numerous conclusions can be drawn and lessons learned. These conclusions, in addition to being more or less generally valid in relation to environmental globalization, are worth considering in the further study and addressing of this dangerous process.

Research on anthropogenic climate change has been characterized by lengthy and sometimes heated scientific debate. Much more detailed observational data and versatile analysis by means of complex climate models were needed to strengthen the level of certainty about the existence of this global process and its causal relationships. International and interdisciplinary cooperation played a major role in this scientific exploration. All this led to the global 'climate problem' appearing on the international political scene and the beginning of the formulation of common goals, policies and measures to tackle this global hazard.

- Scientific research into human interference with the climate system and its significant, far-reaching consequences dates back more than a century. During the long period of these investigations, numerous contradictory hypotheses, propositions, and statements came to light, whose advocates argued for or against the validity of one or another view. In the case of complex problems (such as this planetary-scale one), this is the nature of scientific exploration and can

[717] "Article 9: 1. Developed country Parties shall provide financial resources to assist developing country Parties with respect to both mitigation and adaptation in continuation of their existing obligations under the Convention. 2. Other Parties are encouraged to provide or continue to provide such support voluntarily. …"

[718] [Schneider & Kuntz-Duriseti, 2002: p. 54]

lead to deeper understanding. In other words, doubt and skepticism, supported by well-founded arguments regarding claims and their validity were and remain an important element of the discovery of scientific truth,[719] and this also applies to the problematic discussed here.

- In such systems, which are driven by a variety of external and internal factors (driving forces), it is particularly important to indicate the degree of justification, 'degree of certainty' or level of plausibility of statements about cause-and-effect relationships, changes in the state of the system and scenarios concerning its evolution.[720] Conversely, uncertainties have also been clearly illustrated by the indicators of presumed implications of these global changes, such as global surface temperature or sea level. This is because their (rising) trends were not easily detectable against the background of the high variability of these 'signals' over long periods of time (the phenomenon called a low signal-to-noise ratio). Depending on the level of these certainties/uncertainties, it may be reasonable or appropriate to refer to the precautionary principle and rely on it in climate policy decisions (as occurred in connection with the convention on climate change).

  All the above-mentioned complications in the scientific investigation process and some other (socioeconomic, political, technological) factors may explain the large differences in the duration of time from the more-or-less clear identification of various large-scale anthropogenic hazardous processes to the first international policy responses. For instance, compared to the environmental acidification ('acid rain') and ozone layer depletion problems concerning which a decade-long period elapsed between the determination of their causes and the conclusion of relevant international agreements, in the case of climate change, this required a much longer period.[721]

- The outcomes of the observation, analysis, modeling, and impact assessment programs, the conclusions adopted following the discussions at international research conferences, and the comprehensive assessment reports on climate change created the basis on which the policymaking community could accept that this was no longer a scientific hypothesis, but an actual and dangerous matter. In the course of the development and implementation of international climate policy programs and agreements, the results and recommendations of the scientific community on climate change were the key sources, but many other environmental, economic, and social aspects were also taken into consideration.

International climate policy cooperation accelerated from the second half of the 1980s onwards, and its courses of action, policy areas, and legal provisions became more diverse. The achievements are primarily demonstrated by the four international legal instruments to date, the multicomponent institutional system associated with them, and the activities of numerous organizations, mainly belonging to the UN family, related to this topic. Of course, attention has had to be paid to the widely differing situations of individual countries/societies.

- The variability of the global 'political climate' has had a serious impact not only on international environmental policy in general since the late 1960s but also on the development of climate policy specifically, giving rise to its 'fluctuating' ('semi-cycling') nature. Since the second half of the 1980s, environmental protection in general, and climate change in particular, have been on the agenda of world politics with greater emphasis. But the last decades have also been characterized

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[719] "Le scepticisme est le premier pas vers la vérité". (Denis Diderot, 1746: Pensées philosophiques)

[720] "The degree of certainty in key findings in this assessment is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence […] and, when possible, probabilistically with a quantified likelihood". [IPCC, 2013/WG-I: p. 4]

[721] As regards the environmental acidification ('acid rain') issue, following the recognition of its potential cause in 1968, a framework-type convention was adopted in 1979, and in 1985, the first sulfur protocol with specific goals was approved. Similarly, after the identification of the atmospheric emission of freons as a potential cause of ozone depletion in 1974, a framework-type convention was first drawn up in 1985, followed by the ozone layer protection protocol containing very specific provisions in 1987. In comparison, from the beginning of the late 19th century's publications about human activities affecting the climate system until the conclusion of the framework convention (UNFCCC, 1992), nearly a century passed (if we only count from the much more specific analysis published in the 1930s, it is still about half a century).

by fluctuations in international climate policy commitment and collaboration. For example, initially productive years (approximately 1988-1997) were followed by a kind of 'climate policy apathy', which was overcome, at least for a while, with the successful negotiation rounds of the first half of the 2010s.

- The general approach to this climatic problem area and the formulation and adoption of international response policies and measures in the 1990s were facilitated by some principles, solutions, and means previously introduced to address other environmental issues, the 'repetitive' application of which could thus be agreed on more easily by referring to those precedents. (These included, e.g., the principles related to responsibility and precaution/prevention, the gradual tightening of goals/targets and obligations, the international financing mechanisms supporting the implementation of commitments by certain groups of Parties, etc.). However, global climate change proved to be much more complex and more difficult to handle.
- This environmental problem affects numerous key economic sectors, either as they are major sources of greenhouse gas emissions and/or 'suffer' from the increasing effects of changing climatic conditions. (Concerning the former, the energy sector, transport, several branches of industrial production, agriculture, and forestry, among others, should be mentioned, while in relation to the latter, almost all of the aforementioned, but also healthcare and water management, due to their high level of exposure, especially to extreme events amplified by climate change.) In view of this, economy-wide mitigation and adaptation policies and measures have become necessary, both at the international and national levels; however, these actions depend on the very different – but also gradually changing – situations of individual regions and countries.
- The above-described dichotomy has also arisen in a broader context in the form of a dilemma regarding the relationship between efforts to mitigate climate change on the one hand and preparing for changing climate and related environmental conditions on the other, i.e., concerning which task is considered more pressing or more solvable: moderating further hazardous global changes or rather adapting to their already seemingly unavoidable implications. Of course, these challenges have varied to a large extent from nation to nation. During international negotiations, a consensus has been reached on the urgency of reducing this global environmental burden based on the recognition that adaptation would become impossible or at least much more complicated in many places if the extent and pace of change in environmental conditions exceeded critical boundaries. In addition to the expectation that all parties participate in controlling greenhouse gas emissions, taking into account their respective responsibilities and abilities, there has also been unanimous acceptance of the need to improve 'resilience' and adaptability to adverse impacts.
- Like other large-scale environment-society interactions, the 'climate problem' was further compounded by the fact that it has been strongly influenced by globalization, especially rapidly changing global economic and political relations and the growing interdependence of societies. As for changing world political conditions (the 'world order'), when the convention on climate change was being developed (1991/92), it was still possible to reach agreement on differentiated obligations according to the 'tripartite' division of the world,[722] but in the few decades that have passed since then, the situation has changed radically: this is also indicated by the significant change in the shares attributable to individual countries and groups of countries of the rising global environmental burden. For this reason, the previous approach could not be continued, and new 'realities' (e.g., in terms of the proportions of global GHG emissions and the capabilities of addressing this hazard and its implications) were better reflected in negotiations conducted in the first half of the 2010s, followed by the adoption of the new climate agreement (2015).

Technological developments have had a variety of effects on greenhouse gas emissions and adaptation to changing climatic conditions, but they have also resulted in a kind of development-vs-vulnerability paradox.

[722] The groups of developed and developing countries, and countries with economies in transition.

- Technological innovations have had and will obviously continue to have both beneficial and detrimental environmental impacts. For the more in-depth scientific exploration of globalizing environmental processes, it has proven essential to expand and modernize environmental monitoring networks and develop information transmission, processing systems, and other hard- and software tools for research activities. This includes inter alia the techniques used for paleoclimatological studies, the determination of the abundance and absorption properties of atmospheric trace elements, upper atmosphere and satellite observations, and the application of complex numerical climate models. At the same time, other technological advances have inadvertently contributed to even greater and more injurious environmental impacts, including impacts on the climate system.
- The options for reducing emissions, including, above all, limiting or even phasing out the use of fossil fuels, increasing the efficiency of energy production and consumption, rational energy saving, and the better utilization of renewables, received special attention during previous and the most recent international climate policy negotiations. This starts from the assumption that due to the continuous increase in global emissions, 'end-of-pipe' solutions may also be indispensable in curbing the increase in the atmospheric carbon dioxide concentration, such as various 'greenhouse gas removal' procedures (including carbon capture, storage, or utilization technologies), the development and limitations of which have already been extensively discussed[723]; however, these options have also been subject to serious criticism.
- Climate protection measures so far have not been able to offset the adverse influences of unsustainable consumption and production patterns of the development process, which also threaten the stability of the global climate system. In this sense, it can be seen as a development paradox. Namely, certain technological developments and applications implemented in the interests of socioeconomic progress and well-being – with their unintended side effects – may not reduce but could even increase the vulnerability of societies to natural disasters, extreme environmental events, crises of economic origin, and trend-like changes that manifest themselves in this way, including the rapidly changing climatic conditions.[724]

The differences between the specific goals of climate protection interventions recommended by climate science and the concrete goals adopted by policymakers – and even more so, their actual implementation – have not diminished much in recent decades. The intensification of this global environmental problem, revealed by the further increase in aggregate GHG emissions and the decrease in the related sink capacities, has played a role in this deep science-policy gap, as has the fluctuation in political commitment regarding this matter in many countries, as well as the 'inertia' of the unsustainable consumption and production patterns responsible in general for growing environmental pressures.

- Recent assessment reports confirmed this discrepancy: that is, the major divergence of global policy responses from science-based recommendations, both in terms of emission reductions and preparation for changes in the state of the climate system.[725] The policy projections/plans submitted by countries as part of their Nationally Determined Contributions (NDCs) represent a somewhat positive development because, in light of their global aggregation, it still seems possible that anthropogenic (net) greenhouse gas emissions will cease to increase sometime

[723] [e.g., IPCC/WG-I, 2021: p. AVII-37; IPCC/WG-III, 2022: p. SPM-32].

[724] "Can we survive technology?" [Neumann, 1955] "The lessons learned from failure to carry out thoughtful technological assessment of possible deleterious side effects of substantial expansion in a major technological endeavour should not be disregarded." [WCP, 1981: p. 3]. This paradox was also referred to by the author of this book [Faragó, 1981a, 1981b; Faragó, 2021].

[725] "Since the twenty-sixth UN Climate Change Conference of the Parties (COP 26), there has been very limited progress in reducing the immense emissions gap for 2030. […] Emissions under current policies are projected to reach 58 $GtCO_2e$ in 2030. This is 3 $GtCO_2e$ higher than the estimate of last year's report." [UNEP/EGR, 2022: pp. xvi, xix] "Global efforts in adaptation planning, financing and implementation continue to make incremental progress but fail to keep pace with increasing climate risks." [UNEP/AGR, 2022: p. xiii]

before the middle of this century (although these commitments cannot be considered obligations in the sense of international law).[726]

- However, the achievement of the time-bound global emission reduction targets deemed necessary to avoid exceeding the climate change limitation thresholds set out in the *Paris Agreement* (expressed in terms of temperature rise thresholds) would require extremely decisive measures.[727] This 'science-policy gap' and the 'implementation gap' are somewhat narrower if the projections of all countries that have made 'net zero pledges' are also taken into account[728] and, of course, if all the measures listed in NDCs are fulfilled.[729]

* * *

Overall, international climate policy cooperation has undergone remarkable development over the past few decades; however, the commitments adopted and actions implemented until now are far from sufficient to curb this dangerous process.

- International climate policy cooperation has become multifaceted. In addition to the four legal instruments, a large number of complementary programs have been approved, and cooperation with the scientific community has also developed. The established cooperation frameworks and mechanisms are, in principle, an adequate basis for properly managing this problem, but the specific goals, policies, and measures that have been adopted are not sufficient, and nor is their implementation effective enough.
- The 'signals' – i.e., the trends demonstrated by key indicators – speak for themselves: the atmospheric abundance of key greenhouse gases continues to grow rapidly, global surface temperature increases have recently reached record high values, global mean sea level is also rising unabated, glaciers are retreating, etc.[730] It is also evident that the 'climate problem' does not exist in isolation and cannot be solved independently, as it is significantly interconnected and interacts with numerous other harmful, large-scale human-induced environmental processes.

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[726] "Total global GHG emissions (without LULUCF) taking into account implementation of the latest NDCs are estimated to be around […] 52.4 (49.1–55.7) $GtCO_2eq$ in 2030, which are […] 50.8 per cent higher than in 1990, 10.6 per cent higher than in 2010 and 0.3 per cent lower than in 2019, as well as 1.9 per cent lower than the estimated level for 2025, indicating the possibility of global emissions peaking before 2030." [UNFCCC, 2022: p. 5]

[727] "All global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, and those that limit warming to 2°C (>67%) involve rapid and deep and in most cases immediate GHG emission reductions in all sectors." [IPCC/WG III, 2022: p. SPM-32] "(A.4.3) A substantial 'emissions gap' exists between global GHG emissions in 2030 associated with the implementation of NDCs announced prior to COP26 and those associated with modelled mitigation pathways that limit warming to 1.5°C (>50%) with no or limited overshoot or limit warming to 2°C (>67%) assuming immediate action […] (C.1.3) Continued emissions will further affect all major climate system components, and many changes will be irreversible on centennial to millennial time scales and become larger with increasing global warming." [IPCC/SYR, 2023: Summary for Policymakers]

[728] For example, the EU Member States collectively were committed to achieving 'climate neutrality' by mid-century.

[729] "The absolute difference in the level of emissions by 2030 according to the latest NDCs and the [relevant] IPCC scenarios is sizeable […]. However, assuming full implementation of all latest NDCs, including all conditional elements, the gap is slightly narrowed …" [UNFCCC, 2024: par. 10; par. 14]

[730] "2023 was the warmest year on record at 1.45 ± 0.12 °C above the pre-industrial average. Concentrations of the three main greenhouse gases – carbon dioxide, methane and nitrous oxide – reached record-high observed levels in 2022. Real-time data show that levels continued to increase in 2023. […] Global mean sea level reached a record high. […] Preliminary data from the global set of reference glaciers for the hydrological year 2022–2023 show they experienced the largest loss of ice on record (1950–2023) …" [WMO, 2024: p. 2]. (According to WMO communication on Jan. 10, 2025: "The global average surface temperature was 1.55 °C (with a margin of uncertainty of ± 0.13 °C) above the 1850-1900 average […] This means that we have likely just experienced the first calendar year with a global mean temperature of more than 1.5°C above the 1850-1900 average.")

- More ‘ambitious’ and effective interventions are needed because even after the complete cessation of human interference with the global climate, the changes that have started in this planetary environmental system and their associated serious consequences may persist for a very long time.[731]

[731] “A set of well-mixed greenhouse gases with long atmospheric lifetimes. This set of compounds includes carbon dioxide (CO_2) and nitrous oxide (N_2O), together with some fluorinated gases. […] These compounds accumulate in the atmosphere at decadal to centennial timescales, and their effect on climate hence persists for decades to centuries after their emission.” [IPCC/WG-I, 2021: p. AVII-37]

EPILOGUE

The perilous global environmental processes and our responses to them, discussed in the thematic chapters of this book, share many commonalities. These include, among others, a 'bumpy' road to their recognition, the complications of identifying their causes and establishing cause-effect relationships, the importance of having an appropriate science-policy interface, and the different priorities and fluctuating commitment of decision-makers to develop and implement policy and legal instruments to address these global hazards. Some of these shared findings are summarized below.

- ***The process of cognition***. In the course of production and consumption and other lifestyle-related activities carried out by societies, natural resources have been exploited and utilized, and pollutants released into the environment that have caused harm to human health and the ecosystems at a rapidly increasing rate. This has occurred without realizing the risky implications for a long time, or considering them negligible compared to the usefulness of the activities concerned. These adverse consequences apply similarly to contamination resulting from the widespread use of toxic heavy metals (especially mercury, lead, and their compounds), hazardous chemicals and waste, and atmospheric emissions of ozone-depleting substances and greenhouse gases. It is extremely instructive to identify the main moments and turning points in the scientific exploration of these threats for each of the topics under consideration. In the course of scientific research, the understanding of these environmental problems and their detrimental impacts has crystallized, often amid contradictory assumptions, the raising of arguments and counterarguments, and sometimes heated expert debates. In all these cases, the increasingly precise observations and development of monitoring systems have played a crucial role.
- ***Gradual progress towards achieving certainty and taking action.*** With all these globalizing environmental issues, some 'omens' (that is, extraordinary phenomena and their socioeconomic impacts) could be perceived as possible signs of an emerging or already ongoing potentially dangerous change in the state of the planetary environment – our common planetary home – brought about by natural phenomena and/or human involvement. Paying attention to these signs facilitated the initiation of more in-depth investigations and international discussions on the need to take at least some precautionary steps. More definitive recommendations, goals, and measures could then be adopted based on more well-founded knowledge regarding the pertinent environmental peril or information indicating the inadequacy of previous interventions. This gradualism was evident in the protection of the ozone layer, as well as in the tightening of regulations of international trade in hazardous wastes and the phased strengthening of global climate policies.
- ***Interrelations in global processes.*** The environmental matters analyzed here are not independent from each other either in terms of their root causes or consequences, and thus cannot be solved in isolation. The environmental aspects of human activities (which are often analyzed separately) are strongly intertwined, and their aggregate impact is a fundamental factor in the natural living conditions of societies. For this reason, attention must be paid to the connections and interactions among these global-scale issues. Accordingly, a comprehensive (holistic) approach should be used to identify and examine those human activities that burden the environment with hazardous chemicals and waste, and that directly or indirectly affect the climate, the ozone layer, and terrestrial and marine ecosystems. At the same time, this is the only way to ensure that response policies and measures developed within international programs and agreements to address a specific global problem do not inadvertently lead to the emergence or exacerbation of another

harmful phenomenon. From this perspective, a very striking example was when the solutions first introduced to save the ozone layer – the substitution of substances that were particularly harmful to the ozone layer – contributed to the strengthening of another environmentally damaging process, the atmospheric greenhouse effect.

- ***Primacy of prevention***. In the case of each global environmental issue discussed in this book, the priority of prevention is of key importance – that is, above all, the reduction or elimination of the identified environmentally harmful human interference. In addition, in parallel, it is essential to prepare for and adapt to already inevitable and potentially adverse changes in environmental conditions, including by strengthening resilience. This 'duality' arose for different reasons, especially in connection with climate change and ozone layer depletion. However, it also became clear that adaptation (or adaptability) has its limits, suggesting that it is increasingly difficult and only to a limited extent possible to adapt to accelerating changes in environmental conditions. Due to the different historical responsibilities borne by individual societies for these global problems and their varying capabilities to address them, developed and developing countries, in particular, have understandably represented quite different positions in this regard.
- ***Science-policy interface.*** The strengthening of cooperation between the representatives of the scientific and policy-making communities has been of decisive importance in understanding these environmental hazards and identifying the appropriate policy responses to cope with them. In addition, both governmental and non-governmental (stakeholder) organizations have also played essential roles in this regard, albeit in different ways and with different means.
- ***Compromises***. The international recommendations, programs, and agreements aimed at tackling such extensive environmental problems could only be created at the cost of serious compromises. This was primarily due to the very different situations and interests of the countries, which led to fundamental differences not only in their commitments but also in actual implementation. The result of this was the often significant discrepancy between the goals/targets recommended by scientists and the more moderate ones commonly accepted during the political negotiations and, as concerns the latter, even the failure to achieve them. Although in a very different way and to a very different extent, this has happened in relation to all the programs and agreements referred to in this book (but least of all with the international cooperation on ozone layer protection, which is most frequently referred to in this respect).
- ***The global political atmosphere***. The status and effectiveness of international environmental cooperation have not only depended on the science-based awareness of emerging environmental hazards, but also on the international political situation (e.g., during and after the Cold War period and its several-year 'détente').
- ***The healing of the damaged environment may take a very long time, if it is at all possible***. Not only has the unfolding, globalization, scientific recognition of human-caused environmental harms, the search for appropriate policy responses, and the establishment of consensus about them taken a long time, but it may take even longer to curb these dangerous processes and to achieve again a safe state of the damaged environmental component. This is clearly demonstrated in the case of the gradual elimination of toxic heavy metal applications, overcoming the threat to the ozone layer (thereby the slow regeneration of the 'ozone shield'), mitigating the global environmental release of hazardous pollutants and waste, and coping with accelerating climate change.
- ***Public awareness*** concerning such environmental problems plays a key role in their proper management. In this regard, the significance of education and scientific communication should be highlighted. From this perspective, it is instructive to trace the findings of the researchers quoted in this book, as they indicated the expansion of scientific knowledge about the respective environmental issues and how these have influenced not only the cooperation between science

and politics, but also the ‘enlightenment’ of societies regarding these environmental problems and in general, the understanding of the importance of their living in harmony with nature.

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Chapter 2

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INTERNATIONAL AGREEMENTS

ADN, 2000	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
ADR, 1957	European Agreement concerning the International Carriage of Dangerous Goods by Road
AEWA, 1995	Agreement on the Conservation of African-Eurasian Migratory Waterbirds
ATS, 1959, 1991	The Antarctic Treaty; Protocol on Environmental Protection (Antarctic Treaty System)
BC, 1989 BC/BBA, 1995	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal; Amendment to the Basel Convention (Basel Ban)
BC/PLC, 1999	Basel Protocol on Liability and Compensation for Damage Resulting from Transboundary Movements of Hazardous Wastes and their Disposal
BWM, 2004	International Convention for the Control and Management of Ships' Ballast Water and Sediments
CBD, 1992	Convention on Biological Diversity
CFCLR, 1958	Convention on Fishing and Conservation of the Living Resources of the High Seas
CHS, 1958	Convention on the High Seas
CITES, 1973	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLC, 1992	International Convention on Oil Pollution Preparedness, Response and Cooperation
CLC-BOPD, 2001	International Convention on Civil Liability for Bunker Oil Pollution Damage
CLNUIW, 1997	Convention on the Law of the Non-navigational uses of Transboundary Watercourses
CLRTAP, 1979	Convention on Long-range Transboundary Air Pollution
CLRTAP/SP, 1985	Protocol on the Reduction of Sulphur Emissions or Their Transboundary Fluxes by at least 30 per cent (Sulphur Protocol)
CLRTAP/NP, 1988	Protocol Concerning the Control of Emissions of Nitrogen Oxides or Their Transboundary Fluxes
CLRTAP/VOC, 1991	Protocol Concerning the Control of Emission of Volatile Organic Compounds or Their Transboundary Fluxes
CLRTAP/SP, 1994	Protocol on Further Reduction of Sulphur Emissions
CLRTAP/HM, 1998	Protocol on Heavy Metals
CLRTAP/POP, 1998	Protocol on Persistent Organic Pollutants
CMS, 1979	Convention on the Conservation of Migratory Species of Wild Animals. (Bonn Convention)
CTEIA, 1992	Convention on the Transboundary Effects of Industrial Accidents
CTWC, 1992	Convention on the Protection and Use of Transboundary Watercourses and International Lakes
DRPC, 1994	Convention on Cooperation for the Protection and Sustainable Use of the Danube River (Danube River Protection Convention)
ECT, 1994	The Energy Charter Treaty, Energy Charter Protocol on Energy Efficiency
ENMOD, 1976	Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques
HNS, 1996	International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea
IATA/DGR, 1953	Dangerous Goods Regulations
ICRW, 1946	International Convention for the Regulation of Whaling
IMO/IMDGC, 1965	International Maritime Dangerous Goods Code
IOPRC, 1990	International Convention on Oil Pollution Preparedness, Response and Co-operation
ITTA, 1983, 1994, 2006	International Tropical Timber Agreement
LC, 1972; LP, 1996	London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter; London Protocol
MARPOL, 1973, 1978	International Convention for the Prevention of Pollution from Ships; MARPOL Protocol
MCM, 2013	Minamata Convention on Mercury
Moon, 1979	Agreement on Control of the Activities of States on the Moon and Other Celestial Bodies (Moon Treaty)
OSPAR, 1992	Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR C.)
OST, 1967	Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty)
OTIF/RID, 1980	Regulations concerning the International Carriage of Dangerous Goods by Rail

RC, 1998	Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade
RCW, 1971	Convention on Wetlands of International Importance Especially as Waterfowl Habitat. (Ramsar C.)
SC, 2001	Stockholm Convention on Persistent Organic Pollutants
SLC, 1971	Convention on International Liability for Damage Caused by Space Objects (Space Liability C.)
SOLAS, 1974	International Convention for the Safety of Life at Sea
UNCCD, 1994	UN Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa
UNCLOS, 1982	United Nations Convention on the Law of the Sea
UNCLOS/BBNJ, 2023	Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction
UNFCCC, 1992	UN Framework Convention on Climate Change
UNFCCC/KP, 1997	Kyoto Protocol
UNFCCC/DA, 2012	Doha Amendment to the Kyoto Protocol
UNFCCC/PA, 2015	Paris Agreement
UNWC, 1997	Convention on the Law of the Non-navigational Uses of International Watercourses
VCPO, 1985	Vienna Convention for the Protection of the Ozone Layer
VCPO/MP, 1987	Montreal Protocol on Substances that Deplete the Ozone Layer
WHC, 1972	Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention)

ACRONYMS

ADN	European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways
ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road
AF	Adaptation Fund
ASGM	Artisanal and Small-scale Gold Mining
BAPMoN	Background Air Pollution Monitoring System
CBD	Convention on Biological Diversity
CCOL	Co-ordinating Committee on the Ozone Layer
CEDRE	Centre de documentation, de recherche et d'expérimentations sur les pollutions accidentelles des eaux / The Centre of Documentation, Research and Experimentation on Accidental Water Pollution
CFC	chlorofluorocarbon
CIC	International Council for Game and Wildlife Conservation (Conseil International de la Chasse)
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLRTAP	Convention on Long-range Transboundary Air Pollution
CMS	Convention on Migratory Species
COSPAR	Committee on Space Research (ICSU)
CSCE	Conference on Security and Co-operation in Europe
DU	Dobson unit
ECSC	European Coal and Steel Community
EEC	European Economic Community
EESC	Equivalent Effective Stratospheric Chlorine
EHC	Environmental Health Criteria
EMEP	European Monitoring and Evaluation Programme
ESA	European Space Agency
FAA	Federal Aviation Administration (USA)
FACE	Federation of Associations for Hunting and Conservation of the EU
GARP	Global Atmospheric Research Programme
GAW	Global Atmosphere Watch (WMO)
GCF	Green Climate Fund
GCO	Global Chemicals Outlook
GEF	Global Environment Facility
GEMS	Global Environmental Monitoring System
GEO	Global Environmental Outlook (UNEP)
GEO	Geostationary Earth Orbit
GEO	Group of Earth Observations
GEOSS	Global Earth Observation System of Systems
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GGGI	Global Green Growth Institute
GHS	Globally Harmonized System of Classification and Labelling of Chemicals (UN)
GMA	Global Mercury Assessment
GMOS	Global Mercury Observation System
GMP	Global Mercury Programme (UNIDO, UNEP)
GO3OS	Global Ozone Observing System
GORMP	Global Ozone Research and Monitoring Project (WMO)
GOS4M	Global Observation System for Mercury
GPML	Global Partnership on Marine Litter
GWP	Global Water Partnership
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HNS	Hazardous and Noxious Substances
IAA	International Academy of Astronautics
IADC	Inter-Agency Space Debris Coordination Committee

IAF	International Astronautical Federation
IAGA	International Association of Geomagnetism and Aeronomy
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICCM	International Conference on Chemical Management
ICdA	International Cadmium Association
ICSU	International Council for Science (International Council of Scientific Unions)
IDNDR	International Decade for Natural Disaster Reduction
IEA	International Energy Agency
IFCS	Intergovernmental Forum on Chemical Safety
IGBP	International Geosphere-Biosphere Programme
IGY	International Geophysical Year
IHDP	International Human Dimension Programme
IISL	International Institute of Space Law
ILO	International Labour Organisation
IMO	International Maritime Organization
INC	International Negotiating Committee
IO3C	International Ozone Commission
IOC	Intergovernmental Oceanographic Commission (UNESCO)
IOMC	Inter-Organization Programme for the Sound Management of Chemicals
IOTP	International Ozone Trends Panel
INCHEM	Internationally Peer Reviewed Chemical Safety Information
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPCP	International Panel on Chemical Pollution
IPCS	International Programme on Chemical Safety
IRPA	International Radiation Protection Association
IRPTC	International Register of Potentially Toxic Chemicals
ITU	International Telecommunication Union
IUCN	World Conservation Union (International Union for Conservation of Nature)
IUGG	International Union of Geodesy and Geophysics
IUPAB	International Union on Pure and Applied Biophysics
LDCF	Least Developed Countries Fund
LEO	Low Earth Orbit
LPA	Global Alliance to Eliminate Lead Paint
MAB	Man and Biosphere
MDG	Millennium Development Goal(s)
MENA	Middle East and North Africa
NASA	National Aeronautics and Space Administration (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PAGE	Partnership for Action on Green Economy (UNEP, ILO, UNDP, UNIDO, UNITAR)
PCFV	Partnership for Clean Fuels and Vehicles
PEDAS	Panel on Potentially Environmentally Detrimental Activities in Space
PIC	Prior Informed Consent
POP	Persistent Organic Pollutant
SAICM	Strategic Approach to International Chemicals Management
SBSTA	Subsidiary Body of Scientific and Technological Advice (UNFCCC)
SCCF	Special Climate Change Fund
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
SDG(s)	Sustainable Development Goal(s)
SST	Supersonic Stratospheric Transport
STS	Space Transportation System
TEAP	Technology and Economic Assessment Panel (Montreal Protocol)
TOMS	Total Ozone Monitoring Satellite
UNCED	UN Conference on Environment and Development
UNCHE	UN Conference on Human Environment
UN/CHS	UN Commission on Human Settlements

UNCHS	UN Centre for Human Settlements (Habitat)
UNCOPUOS	UN Committee on the Peaceful Uses of Outer Space (Space Committee)
UN/CPD	UN Commission on Population and Development
UNCSD	UN Conference on Sustainable Development
UNCTAD	UN Conference on Trade and Development
UNDAC	UN Disaster Assessment and Coordination
UN/DD	United Nations Development Decade
UNDP	UN Development Programme
UNDRR	UN Office for Disaster Risk Reduction
UNECE	UN Economic Commission for Europe
UN/EMG	UN Environment Management Group
UNEP	United Nations Environment Program
UNEP/GC	UNEP Governing Council
UNEP/IRP	UNEP International Resource Panel
UNESCO	UN Educational, Scientific and Cultural Organization
UN/FfD	UN Financing for Development
UNFPA	UN Population Fund (UN Fund for Population Activities)
UNGA	UN General Assembly
UNHRC	UN Human Rights Council
UNIDO	United Nations Industrial Development Organization
UN/OCHA	UN Office for the Coordination of Humanitarian Affairs
UNOOSA	United Nations Office for Outer Space Affairs
UN/SDSN	UN Sustainable Development Solutions Network
UNSG	UN Secretary-General
UN/WWAP	UN World Water Assessment Programme
VCPO	Vienna Convention on Ozone Layer Protection
WCED	World Commission on Environment and Development
WCP	World Climate Programme
WFP	World Food Programme
WMO	World Meteorological Organization
WODC	World Ozone Data Centre
WOUDC	World Ozone and Ultraviolet Radiation Data Centre
WSSD	World Summit on Sustainable Development
WWF	World Wide Fund for Nature (World Wildlife Fund)
WWI	Worldwatch Institute