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*Review*

# Energy Security and Energy Transition to Achieve Carbon Neutrality

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**Abstract:** Successful energy transitions, also referred to as leapfrog development, present enormous prospects for EU nations to become carbon neutral by shifting from fossil fuels to renewable energy sources. Along with climate change, EU countries must address energy security and dependency issues, exacerbated by factors such as the COVID-19 pandemic, rising energy costs, conflicts between Russia and Ukraine, and political instability. Diversifying energy sources, generating renewable energy, increasing energy efficiency, preventing energy waste, and educating the public about environmental issues are proposed as several strategies. The study draws the conclusion that central European countries may transition to a clean energy economy and become carbon neutral on economic and strategic levels by locating alternative clean energy supply sources, reducing energy use, and producing renewable energy. According to the study, the EU energy industry can be decarbonised and attain energy security using three basic strategies, such as supply diversification, energy savings, and quicker adoption of renewable energy to replace fossil fuels. The energy transformation industry still needs to improve energy efficiency, incorporate a circular and sustainable bioeconomy, and support renewable energies, including solar, wind, hydropower, nuclear, and hydrogen.

**Keywords:** energy security; energy efficiency; energy transition; renewable energy; energy trilemma; environmental sustainability; carbon neutrality



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## 1. Introduction

Global energy consumption is estimated to increase by about 80% by 2030, with emerging economies expected to overtake the industrialised world as the leading energy users. Because of the relative availability and environmental sustainability, natural gas is forecasted to be the fastest-growing fuel between 2000 and 2030. Oil consumption will surge further, with the transportation sector accounting for a substantial increase. Renewable energy (RE) will progressively generate electricity, albeit wind and biomass will grow from a minimal base [1]. However, according to the International Renewable Energy Agency (IRENA) [2], RE is projected to provide 90% of all electricity in the world by 2050. In addition, through RE, countries can diversify their economies, protect themselves from price swings, create jobs, and reduce poverty, while easing import dependency [3]. Moreover, RE will significantly contribute to ensuring energy security.

The public debate around decarbonisation, carbon neutrality, and climate policies has gained new impetus worldwide, particularly in the European Union (EU). Droughts, heat waves, heavy rains, floods, landslides, and other extreme weather conditions are becoming more prevalent worldwide, including in Europe. Ocean acidification, rising sea levels, and biodiversity losses are also consequences of climate change [4]. Global greenhouse gas emissions account for over 75%, and carbon dioxide emissions are nearly 90% attributed to fossil fuels. It is essential to reduce greenhouse gas emissions by almost half by 2030 and to reach net-zero by 2050 to avoid the most severe impacts of climate change [3]. Concern over energy security and carbon neutrality, coupled with the rising demand for alternative clean energy, has led EU countries to seek alternative new energy sources. It is possible to reduce carbon emissions and pursue carbon neutrality by reducing emissions in other sectors. Through the diversification of energy sources, investment in renewables and other clean technologies, and adoption of low-carbon practices, we can achieve this goal [4].

In addition, effectively combatting climate change and achieving carbon neutrality needs an energy transition. This energy transition must ensure a sustainable future and leave the next generation with enough energy to meet needs. Previous research by Jacobson et al. and Delucchi et al. [5,6] has found that transitioning the entire world could be technically and economically possible. Nevertheless, other studies explored similar concerns, but for specific countries or industries, or just carbon emission reductions, in general, rather than reducing air pollution and carbon emissions [7].

The EU energy industry will face significant challenges over the next few decades. As typical cases, in this paper, new ways of achieving energy security and carbon neutrality transition in CEU countries have been selected for the following reasons: increasing fossil fuel scarcity, combatting environmental degradation, establishing energy security, and transitioning to RE generation to achieve carbon neutrality to meet the EU's expanding energy demand. Contending with the challenges will necessitate significant government intervention, effective energy policy, and industry innovation. In addition, European policymakers must accelerate efforts to enter the carbon neutrality era and reduce greenhouse gas (GHG) emissions to zero by 2050.

Based on this context, the paper seeks to provide insight into the empirical factors affecting energy transition to achieve energy security and carbon neutrality at the national level for the CEU. Hence, it contributes to the literature on energy security and carbon neutrality by exploring the relationships between the following facts: (1) diversification of energy sources increases energy availability, (2) increasing renewable energy generation relates to improvement of energy affordability, and (3) conserving energy contributes to the reduction of environmental impact and achieving stability at the country level.

Following the high ranking papers on energy security and carbon neutrality research in recent years, flourishing literature has emerged to identify the energy supply security, low-carbon energy transformation, and energy independency that prompt high energy efficiency and RE deployment at the country level [8,9]. Since then, the idea has expanded to include renewable, carbon-neutral, and environmentally sustainable energy systems, but they still remain limited in scope [10,11]. On the other hand, the EU directive targets reached a 20% share of final energy consumption from renewable energy by 2020 and successfully met its target by consuming 21.3% of energy from renewable sources in 2020 [12]. Achieving the goal will help the member states speed up RE production and use.

Furthermore, most studies aimed at achieving energy security and carbon neutrality focused solely on ensuring an uninterrupted energy supply and lowering carbon emissions [4,7]. In order to achieve energy security and carbon neutrality, few studies have emphasised the diversification of energy sources, RE generation, and energy savings, so this paper attempts to fill that gap.

From our perspective, academics should research three different strategies, in order to achieve energy security and carbon neutrality by 2030. First, diversification from an environmental perspective [13]. The second step is an up to 45% increase of the share of renewable energies [14,15]. The third step is to slash 20% of energy use and avoid energy waste [16,17].

Furthermore, energy prices have hit their highest levels in over a decade, due to Russia's unprovoked invasion of Ukraine, which has led many countries to reassess their energy supplies, security, and carbon neutrality achievement targets.

However, mitigating climate change usually has co-benefits and mutual welfare, in terms of improving the security of energy supplies, such as reducing energy imports, slowing non-renewable resource depletion, and increasing energy diversity [8,18]. Prior research has focused on the advantages of reaching both climate and non-climate energy goals simultaneously [19–21]. Additionally, it is possible to pursue some of these non-environment goals independently; for instance, lowering energy imports can be achieved through environmentally friendly policies, such as limiting energy use by increasing energy efficiency and developing local RE sources or by using high-carbon alternatives, such as boosting the usage of indigenous coal.

Consequently, this review paper seeks to investigate the feasibility of achieving new forms of energy security and carbon neutrality through the energy transition in selected EU member states. We propose relevant strategy and policy framework measures in this context. The current research selected and evaluated Austria, Germany, Hungary, Slovenia, Czechia, Slovakia, Croatia, and Poland, due to their substantial reliance on energy imports and RE's political concerns. Numerous other questions also come up to accomplish the review paper's anticipated goal. Is there a realistic substitute for fossil fuels in renewable energy? Is dependence on energy imports a risk to energy security? What measures and policies must be complied with if carbon neutrality is to be achieved? The solutions to such concerns are tied to an essential aspect of energy imports, the Russian and Ukrainian war, political instability, and climate change. Achieving carbon neutrality, energy security, and sustainability become inextricably linked in long-term situations.

The methodology comprises specific search strategies and article selection criteria tailored to particular research objectives, based on systematic reviews of the existing literature. This review entails a comprehensive assessment of the academic and peer-reviewed literature relevant to energy security and transition towards carbon neutrality from the Scopus, Web of Science, and Google Scholar databases. The way to find peer-reviewed literature is primarily by searching the Web of Science database (both forward and backward search) by search term (individually, Boolean combined). Google and Google Scholar were used to find grey literature and match it with previously identified reports, policy documents, and working papers. The latest updates to the long-standing reports from various organisations (such as International Renewable Energy Agency (IRENA), World Energy Trilemma Index, European Climate Foundation (ECF), International Energy Agency (IEA), Asia Pacific Energy Research Centre (APERC), European Commission (EC), RePowerEU Plan, The World Bank Group) were checked directly from their websites. Microsoft Power BI tool was used to analyze and visualise Eurostat data and Trilemma Rank Index. As EU countries strive for energy security and carbon neutrality, this paper examines critical energy transition approaches. Additionally, it sheds light on the strategy and policy pathways required for energy transition in the eight selected member states of the EU.

## 2. Conceptualisation of Energy Security

Energy security research has expanded beyond its traditional roots during the 1970s oil crisis to encompass a wide range of energy industries and threats. This view contributes to the rethinking of the energy security that has accompanied this progress. Traditional conceptions of energy security include the relative availability, affordability, and safety of energy sources and supplies. Similarly, The IEA defined the energy security concept as "*the uninterrupted availability of energy sources at an affordable price*" [22]. Further, the World Bank Group [15] found energy security on three pillars: energy efficiency, supplier diversity, and price volatility minimisation.

However, Knox-Hayes et al. [23] identified the following eight dimensions of energy security: (1) availability, which encompasses supply stability and affordability; (2) welfare, which encompasses energy justice and ecosystem health; (3) efficiency, which implies marginal energy capacity and bears some resemblance to welfare; (4) affordability, which implies cost affordability and modest energy production and bears some resemblance to among other dimensions; (5) environment, implying equity, environmental quality; (6) transparency, which denotes energy justice, clarity, and awareness; (7) climate, which is intertwined with welfare and the environment and is tied to global climate change; and (8) equity, and dimension overlaps with others.

Similarly, Sovacool and Rafey [24] defined energy security as a set of four dimensions: (1) availability, which involves diversifying fuel sources, qualifying for disruption restoration, and limiting reliance on energy imports; (2) affordability, which comprises making energy services more affordable and minimising price fluctuations; and (3) efficiency and development, which involves increasing energy efficiency, influencing consumer attitudes, and building energy infrastructure; (4) environmental and social sustainability entails safeguarding the environmental resources, as well as societies and subsequent generations.

According to Gasser [25], "*Due to countries' diverse natural resources, political systems, economic welfare, ideologies, geographical positions, and international relations, energy security can mean different things, and the priorities can vary*." These have a lot in common when addressing three pillars of energy security: (1) Availability and accessibility of energy sources (energy independence). (2) Affordability and equity (improve energy efficiency). (3) Stability and sustainability (environmental sustainability). Based on a variety of published conceptions of energy security, it appears that the consistent provision of these three desirable characteristics is a shared attribute. These characteristics form a solid foundation for building future extensions of this topic.

## 3. EU's Energy Performance

Environmental policy researchers and public stakeholders have pushed for "*energy performance*" to be widely used and recognised. Energy efficiency can be better understood by measuring energy performance. Monitoring energy consumption enables users to comprehend and optimise energy usage by making production plan adjustments and behavioural changes that improve efficiency. A growing variety of energy-related regulating mechanisms, such as tradable green certificates [26] and carbon emission permits [27], are being implemented at the firm operations and management levels. Furthermore, energy performance measurement has environmental (diminution of greenhouse gas (GHG) and other pollution emissions), economic (decreased individual utility bills, generates employment, and helps to stabilise electricity prices and volatility), and risk management (fuel price volatility can be stabilised by diversifying utility portfolios) benefits [28].

The World Energy Council (WEC) yearly prepares and publishes the energy trilemma index (ETI), an official indicator for measuring energy performance. Different disciplines and places use the notion of an energy trilemma differently. The ETI has depicted it as a triangle. The complex 'energy trilemma,' consisting of the interconnected, but frequently contradictory, aspirations of energy security, tackling climate change and energy poverty, and poses a significant challenge to global energy governance [29]. Using the energy trilemma index, governments and stakeholders can identify areas where energy policy could be improved and determine the most effective options.

WEC's released ranking is an unrivalled resource and guide for policymakers seeking long-term energy system solutions. Energy security (capability, dependency, and resilience), energy equity (accessibility, affordability, and quality), and environmental sustainability (limiting emissions and degradation, as well as increasing resource efficiency) are the three characteristics on which the WEC rates countries, based on their capability to deliver secure, affordable, and environmentally sustainable energy [30,31]. Their balancing grade represents overall competence in building a sustainable energy mix policy, and the ranking shows how effectively a country balances the trade-offs of the trilemma. Consequently, the selected EU member states were ranked as the most energy-secure countries in the EU in the energy trilemma index in 2021.

The energy security dimension (Figure 1) emphasises the need for a robust energy policy to maximise domestic resources, while diversifying and decarbonising energy systems. Czechia (score 9), Germany (score 10), and Hungary (score 12) are among the top three improving countries on the energy security list. Their strategy involves enhancing energy security and tackling its long-term sustainability, while strengthening the EU's energy mix.

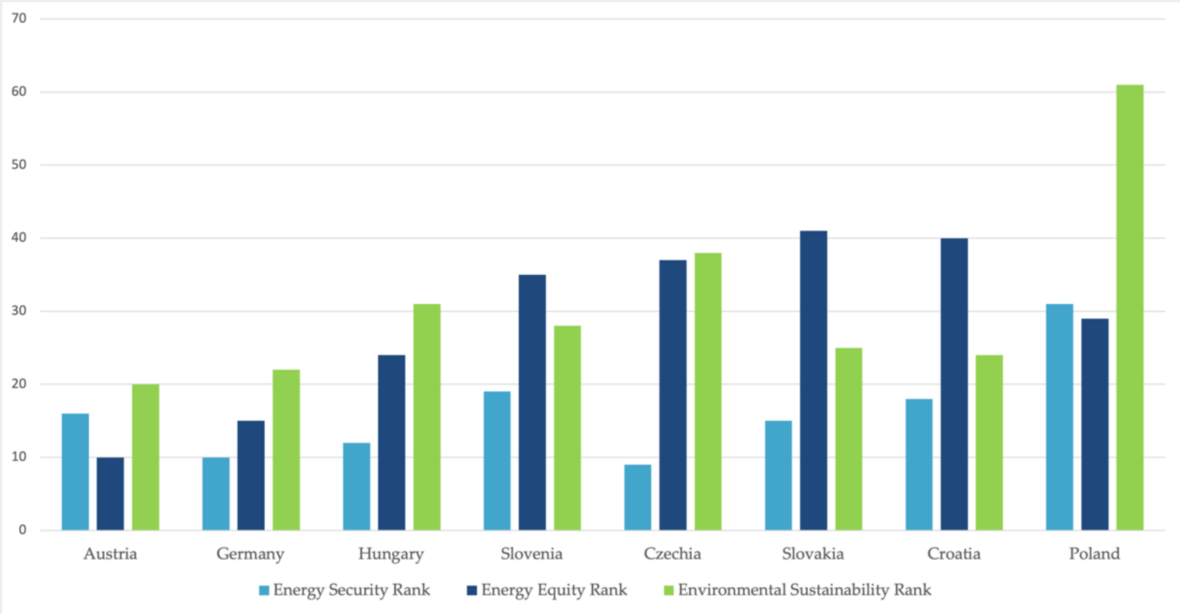


**Figure 1.** Trilemma rank of energy security, energy equity, and environmental sustainability of central European countries in 2021. Notes: 1 score is best, and 100 score is worst. Source: Developed based on The World Energy Council's Trilemma Rank Index, 2021 [32].

Austria and Slovakia scored the same in energy security, but their approaches differed based on their distinct socioeconomic environments. The two countries do not have particularly strong endowments for domestic energy resources, though the Austrian energy mix is more diverse, due to its hydropower potential. Slovaks rely heavily on coal-based energy and have low resources; however, nuclear power is produced in large quantities, which is politically unsuitable in Austria [33].

Croatia has a significant natural resource endowment, compared to low-performing nations, such as Poland and Slovenia, enabling it to diversify and integrate energy with neighbouring countries to drive good performance. Poland had the highest 90% share of fossil fuels in gross available energy among the selected EU countries in 2019. Furthermore, most of the remaining member states had 60% to 80% [34]. However, to achieve a balanced total trilemma score, decarbonisation and diversification should be prioritised.

The energy equity rankings comprise producer countries with low energy costs for their citizens. The EU region ranked high in energy equity in 2021, but the pandemic has revealed societal vulnerabilities and concerns about energy affordability and accessibility. The implicit subsidies made it increasingly difficult to maintain the current decarbonising environment. Austria (score 10), Germany (score 15), and Hungary (score 24) are the top three achievers, in terms of this component. In either direct or indirect form, price subsidies generally hinder energy supply diversification and reduce the trilemma score on other dimensions. The top three countries have programs to increase energy access and make it more affordable for consumers.

Nevertheless, all the best-performing energy equity nations are developed nations with complex and robust energy infrastructures in Europe. Their energy mix continues to diversify as they move increasingly toward zero-carbon energy sources. Besides the apparent sustainability benefits of zero-carbon energy, other factors are driving the transition, such as countries seeking to harness their local natural resources and declining balancing costs. Energy equity countries are challenged with finding the right balance between affordable energy and ensuring equitable access to energy for all citizens.

In terms of environmental sustainability, Austria (score 20), Germany (score 22), and Croatia (score 24) are at the top of the list, demonstrating strong policy efforts to decarbonise and diversify energy systems. The sustainability of our environment is enhanced with a diverse energy system that is backed up by effective regulatory instruments that significantly reduce greenhouse gas emissions and increase energy efficiency. Despite ongoing efforts to reduce carbon emissions from energy generation, ensuring continuous progress in environmental sustainability proved difficult. Austria is the leading contributor to sustainability, followed by Germany, Croatia, and Slovakia, which have dramatically increased their use of renewables for their electricity consumption.

Nevertheless, the Russian and Ukrainian wars will force reshaping the energy transition in the developed world, since climate protection now requires attention to energy security. It will remain unclear which energy source will prevail until more information becomes available. Despite this, an opportunity seems to be lurking in the shadows. It is an opportunity for the world to create a viable, sustainable development plan with a strong decarbonisation agenda [35].

Energy markets worldwide are undergoing unprecedented change as governments strive to decarbonise and adopt more equitable energy transitions to help the global economy rebound from the pandemic's economic impact. Countries that have not yet decarbonised their energy mix can benefit from minimising energy intensity. However, humanising the energy transition guarantees inclusive decarbonisation, leaving no community behind.

However, those objectives have been deferred by the exorbitant energy prices, particularly natural gas, brought on by Russia's invasion of Ukraine. Russia's energy resources, on which Europe depends, are now not just unreliable, but also unwanted, due to the war [35].

The energy market typically outpaces regulations and policies in the energy sector. However, sometimes they change the game by rethinking energy markets to take advantage of new technologies and industry standards. The energy trilemma index must be adapted to reflect the evolving energy industry and keep up with database and indicator changes to remain relevant and contemporary. Furthermore, the significance of the COVID-19 epidemic must not be overlooked [36]. The challenges and opportunities provided by post-pandemic recovery are expected to change energy policies and the energy transition agenda. The trilemma can be used to guide the conversation toward a more secure, equitable, and sustainable energy future.

## 4. The REPowerEU Plan: Securing Affordable and Sustainable Energy for Europe

In addition to imposing economic sanctions on Russia, the United States, the European Union, and others plan to wean off fossil fuel exports from that country. European leaders are grappling with reducing their reliance on Russia as their energy supplier. Europe must achieve decarbonisation as its long-term goal, which will allow Europe to end its dependence on Russia, while meeting its climate objectives simultaneously. To achieve this, RE is rapidly substituting fossil fuels in national and regional electricity systems. The RepowerEU plan can drastically reduce the need for energy imports from Russia and eliminate fossil fuels for member states [37].

Moreover, the transition to clean and RE energy must be accelerated by the EU member states' united efforts. The Paris Agreement's target of keeping global warming to 1.5 °C above pre-industrial temperatures must be achieved through this effort.

Europe continues to lead the way in resolving the trilemma, taking eight of the top ten spots in 2021's Index. While the pandemic's consequences are still being felt, the region's general energy agenda is focused on sustainability. The approach to generating low-carbon energy is being driven by renewables, which contributed 38% of the EU's electricity in 2020, and outpacing is also high on the policy agenda outside of the EU27. Diversification and interconnectivity are helping to improve energy security, but there is still pressure to release coal from the energy mix.

As a result of Russia's invasion of Ukraine and the disruption of the global energy market, the European Commission drafted the REPowerEU plan (Figure 2).

European energy security is dependent on Russian energy imports. EU must become energy independent to achieve the required level of energy security. However, energy security is currently being endangered by the Russian–Ukrainian war. Through energy savings, supply diversification, and quicker adoption of RE to replace fossil fuels in homes, businesses, and power generation, the REPowerEU plan's policies can help achieve this objective [38]. Furthermore, the aims of the Green Deal have never been as crucial as today. Petroleum products, including crude oil, the primary component, accounted for nearly two-thirds of total energy imports into the EU in 2019, responsible for roughly two-thirds of total energy imports, followed by 27% of natural gas and 6% of solid fossil fuels [39,40].

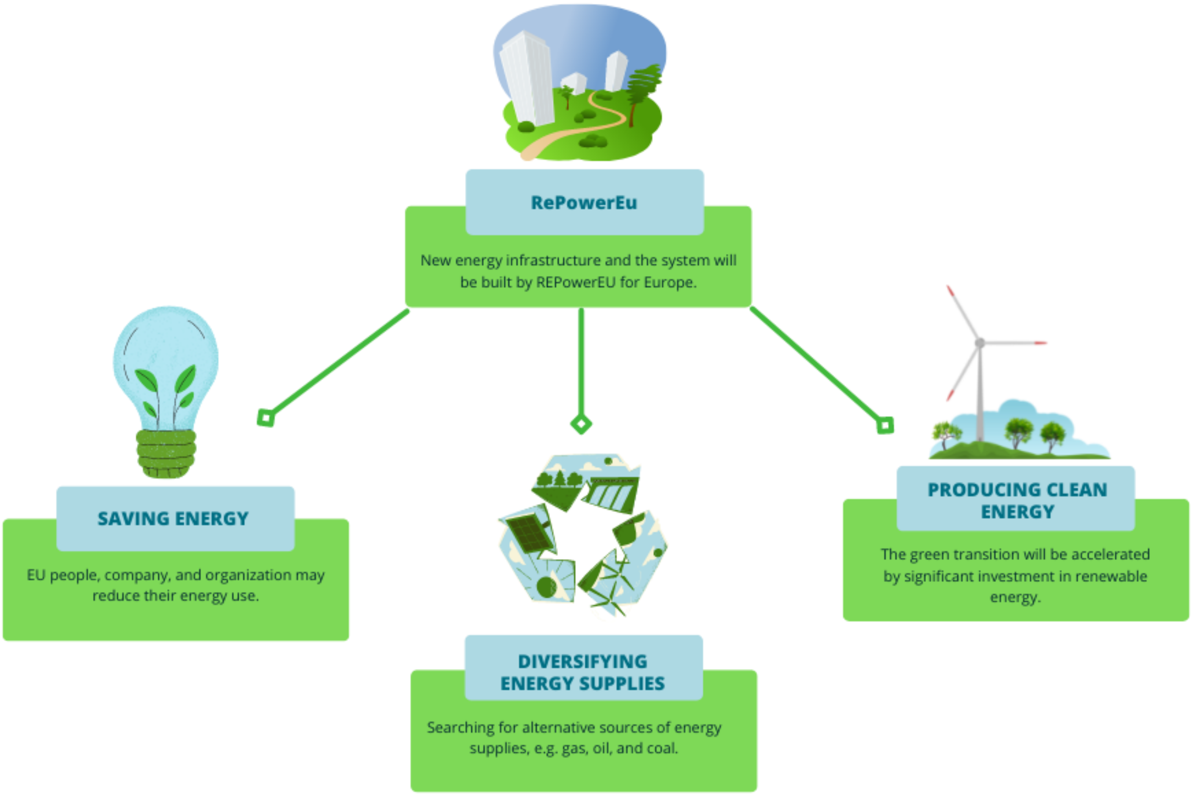


**Figure 2.** Graphical presentation of REPowerEU plan. Notes: Short-term and medium-term actions are expected to be completed by 2027. Source: Developed by Authors, based on the REPowerEU plan, 2022 [38].

Furthermore, if we measure the EU energy performance with three features of the energy trilemma of WEC, then the EU's energy system is not secure for the long term. Traditional energy production in central Europe has relied on non-renewable or fossil fuel-based energy sources [41,42]. Petroleum, coal, and natural gas dominate the world's energy supply. As we move toward a clean energy future, these three fossil fuels currently provide 87% of world energy and 71% of the EU's energy [34]. Therefore, the EU's domestic fossil fuel resources significantly affect its energy dependency. Additionally, European energy security is dependent on imports.

Figure 3 shows the energy imports for the EU in 2019 amounted to 60.6%, which means that over half of the EU energy requirements were met by net imports [43]. As we can see in 2019, selected EU countries are most reliant on Russia for crude oil, natural gas, and solid fuels imports, with Austria (71.62%), Czechia (40.82%), and Hungary (69.71%) being the top importers, in terms of crude oil and natural gas imports. Since 2000, when it was only 56%, its reliance on energy imports increased [44]. Compared to 2000, most CEU countries' import dependency percentages increased in 2019. In the case of Slovenia, the percentage of energy imports was unchanged. Regarding energy imports, Czechia at 79.80% and Poland at 321.91% had significantly increased energy imports from Russia. However, EU energy is making strides to minimise its reliance on imported energy and make more remarkable energy progress (Box 1).

**Box 1.** Progress made by the European Union (EU) in the energy sector [38,44].

- REPowerEU is a sustainable, affordable, and secure energy plan that was launched in 2022 by the European Union.
- The rapid deployment of solar and wind energy projects will reduce gas imports by around 50 billion cubic meters.
- A 45% renewable energy target set for the European Union by 2030.
- EU-wide energy efficiency target increased from 9% to 13% by 2030.
- Boost decarbonisation of the industrial sector through frontloaded projects worth EUR 3 billion.
- The EU's greenhouse gas (GHG) emissions have declined by 31% from 1990 to 2020.
- Renewables overtake fossil fuels. A total of 38% of EU electricity comes from renewables, with 37% from fossil fuels and 25% from nuclear power.
- Renewable energy sources are expected to grow by an average of 22% of the entire energy mix in the EU.
- Primary energy consumption dropped by 1.9% in the EU in 2019, as did final energy consumption by 0.6%, comparable to 2018.
- Compared to 58.2% in 2018 and 56% in 2000, the EU's overall energy import dependency increased to 60.6% in 2019.

Source*:* REPowerEU 2022 [38] and European Commission 2021 [44]

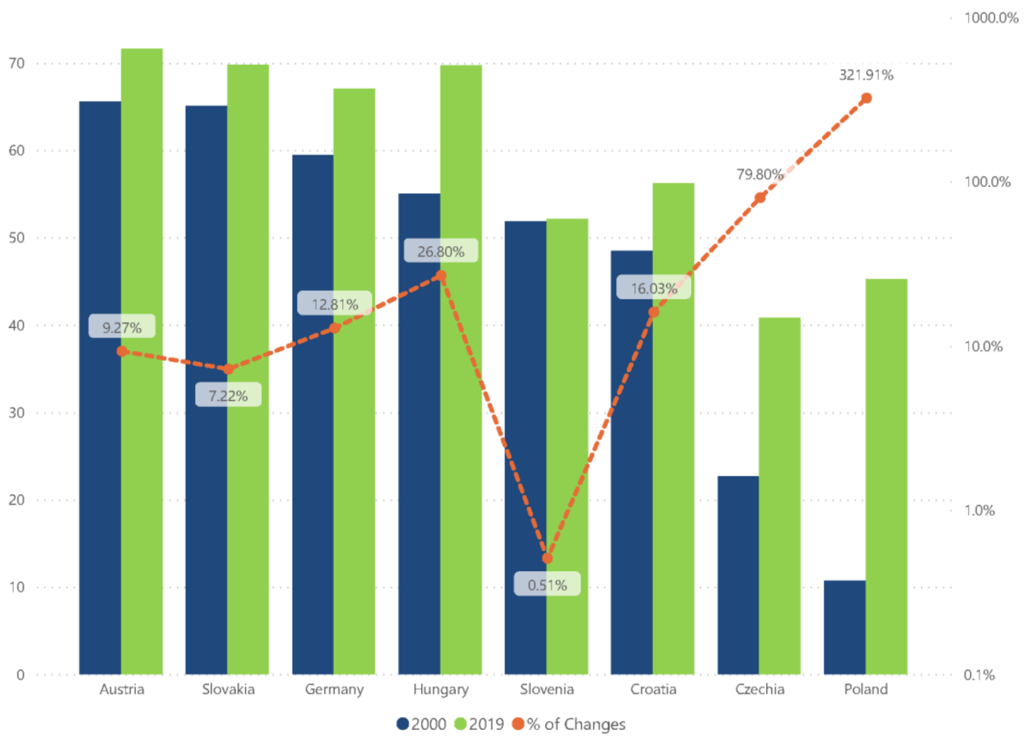


**Figure 3.** Energy dependency rate (%) of central European countries in 2021. Source: Developed based on Eurostat data, 2019 [45].

Some exceptions exist to reducing energy import dependency and relying on fossil fuels. Even though Norway has a small population and abundant hydropower, it achieves 98% of its energy needs through hydropower. In addition to being the world's second-largest producer of natural gas and Europe's top oil exporter, Norway's North Sea reserves supply the rest of its energy needs [46].

The EU will be able to reduce its dependence on Russian fossil fuels by implementing the REPowerEU plan. The share of renewables in the energy mix of the EU is about 22%. The EU produces around 40% of its energy, while 60% is imported. Approximately 40% of Europe's gas consumption, 27% of its oil imports, and 46% of its coal imports were imported from Russia in 2021. A total of 62% of energy imports from Russia are worth EUR 99 billion. Before the decade's end, RepowerEU aims to become completely independent from Russian fossil fuels. The main priority to reduce dependence on imports of fossil fuels under the RePowerEU concept is the rapid enlargement of the share of renewables in the energy mix, in addition to increasing energy efficiency. A 55% reduction in GHG emissions by 2030 is expected to be achieved by the targets set for renewable energy and energy efficiency. The Commission is proposing to increase the EU's 2030 target for renewables from the current 40% to 45% and for energy efficiency from the present 9% to 13%. EU legislation speeds up permitting procedures for wind farms and solar panels [37]. As part of the EU Solar Energy Strategy, more than 320 GW of new solar photovoltaics will be installed by 2025, more than twice today's level. As part of the hydrogen strategy, 10 million tonnes of renewable hydrogen would be produced domestically, with 10 million tonnes of renewable hydrogen imported into the EU by 2030 [38].

In addition, EU legislation accelerates work on technical hydrogen standards. As part of the action plan for establishing the industrial biogas and bio-methane partnership, 35 billion cubic meters of biomethane will be produced by 2030, stimulating the renewable gas value chain. Russian fossil fuel imports of 100 billion euros per year must be phased out between 2022 and 2027, requiring additional investments of EUR 210 billion [37].

The primary goals of EU energy policy are sustainability, affordability, and supply security. Non-accomplishment of these policy objectives could disrupt the attainment of energy security goals. Eunju et al. [47] discussed that, in terms of supply disruptions and price volatility, the level of dependency on supply and demand in the energy market leads to higher prices for energy security. The Energy Union strategy, adopted in 2015, establishes a comprehensive framework for the further integration of European energy markets. Their Energy Union strategy includes five interconnected elements: (1) energy security, unity, and trust; (2) a European energy market that is completely integrated; (3) energy efficiency as a means of demand moderation; (4) decarbonisation; and (5) research, innovation, and competitiveness [48]. This framework indicates that all these strategies are geared towards transitioning to RE and sustainability. As the EU's primary energy source, renewable energy sources have surpassed fossil fuels [43]. The market for renewable energy has proven to be resilient, despite the pandemic's effects. EU must continue to invest in RE sources to strengthen EU energy independence.

## 5. Energy Transition to Achieve Carbon Neutrality

The transition to a climate-neutral future is driven by several factors, including EU legislation, such as the European Green Deal, state assistance for R&D, and the desire to minimise reliance on fossil fuels [49].

Sustainable bio economies are required for a climate-neutral future and for achieving the 2050 carbon neutrality target. The goal of the bioeconomy is to transition from "old carbon," which has accumulated over millions of years, to "new carbon," which is biological and renewable, during the next one to ten years. Life forms in a natural setting, that is, in harmony with the atmosphere, produce renewable carbon. Our selected eight CEU countries must incorporate a circular and sustainable bioeconomy into their governmental agendas to make bio-based goods and services more valuable [49].

The evidence for human-made global warming and its potentially catastrophic effects is undeniable. The International Energy Agency (IEA) [50] acknowledged that around two-thirds of greenhouse gas emissions are caused by energy production and consumption, and an "*energy revolution*" encompassing a shift from a high to a low carbon economy is urgently needed. Enhancing energy security will necessitate a global approach that is far-sighted and cooperative, as well as many specific national and international initiatives and actions. In this regard, two challenges stand out: the threat of global warming and its links to the use of fossil fuels; and a considerable percentage of the world's poorest members' lack of access to clean, healthy, and affordable energy, including electricity, which indicates the need for RE sources. However, to overcome the associated risks, we must emphasise energy transition.

The energy transition is "*a pathway toward transforming the global energy sector from fossil-based to zero-carbon by the second half of this century*" [51]. The RE revolution will be among the primary characteristics and factors supporting the transition to a low-carbon economy. The RE trajectory will be the primary factor as a critical driving force for the transition to a low-carbon economy. Natural gas must be used instead of coal, and fossil fuels must transform into nuclear and RE sources [52]. Even though nuclear power is a low-carbon energy source, Japan's Fukushima Daiichi nuclear disaster provided a vivid example of shifting from nuclear energy to other RE sources [53].

Recalling Knox-Hayes et al. [23], the definition of energy security indicates the apparent link between RE and sustainability. RE can improve a minimum three of the following dimensions of energy security examined in the study. Moreover, RE significantly increases environmental quality, particularly in resisting climate change and modest energy production. In the context of the dimensions of energy security outlined by Sovacool et al. [24], RE for electricity production allows for fuel diversity, disruption restoration, reduced reliance on foreign sources, reduced price volatility, and environmental sustainability. Furthermore, using RE has multiple benefits, including lower energy costs, lesser environmental pollution, less reliance on fossil fuels, and more efficient energy production and supply [54,55].

The transition to RE occurs at various intensities throughout EU member states. This pattern reflects their diverse national energy security challenges, resulting in divergent foreign energy policy agendas within the Energy Union [56]. However, the energy transition can transform the global energy system from fossil fuel to zero-carbon. Despite the current global energy transition, further measures are required to curb carbon emissions and prevent climate change. Through energy efficiency initiatives and the deployment of RE sources, carbon emissions can be reduced by 90% [57,58]. Furthermore, RE supplies must be essential to achieving energy security and sustainability.

Although the transition towards RE will significantly impact the EU and the rest of the globe, the associated problems, regarding the transition, undoubtedly influenced the EU's clean energy package targets. In contrast, RE impacts the economy, society, and politics (Box 2).

**Box 2.** The challenges of setting up a renewable energy system [59].

- Solar and wind energy are both dilute fuels that necessitate vast swaths of land. Onshore wind farm construction needs vacant land, which negatively impacts animals.
- Metal, concrete, and any components used in wind turbine installation must be recycled or appropriately rid of as solid waste after 20 to 26 years of service.
- The community frequently resists renewable energy initiatives on a large scale, due to aesthetic concerns and lifestyle disruptions.
- Since wind and sunlight are intermittent, they must store the energy they absorb to serve as a primary energy source.
- Even though renewable energy is becoming more affordable, it still relies on government budgets.

Source: Harjanne et al. [59]

Despite so many issues regarding installing renewable energy systems, "*Smart grid*" technology can be used to enable the efficient control and transfer of renewable energy sources, such as solar, wind, and hydrogen. The smart grid connects various distributed energy resources to the power grid. Eco-friendly smart grid technology could provide both invigorating economic growth and improve electricity distribution to customers worldwide, due to the global demand for greener technologies and alternative energies [60].

Furthermore, the RE transition's environmental effects should be lessened, and the prominence of RE projects must be made more acceptable to society to reap the benefits of the change. However, RE sources, such as solar, wind, and water resources, can be ramped up quickly to build a worldwide energy system that runs solely on clean and renewable energy (Box 3).

**Box 3.** The potential outcomes of transitioning to 100% renewable energy by 2050 [61].

- It can prevent 4–7 million fatalities and millions of diseases caused by air pollution annually.
- It can decrease greenhouse gas emissions to near-zero levels, allowing us to escape many of the dire climate consequences of prolonged use of fossil fuels.
- It will create over 24 million additional permanent, full-time jobs, including replacing all jobs lost in the fossil fuel industry.
- RE transition can maintain global energy price stability, while lowering consumer energy expenses.
- The transition will increase electricity access to 4 billion people, who would otherwise be in energy poverty.
- RE transition will minimise the threat of terrorism and the disastrous consequences of massive, centralised energy plants.

Source: Jacobson, M.Z. et al. [61]

Globally, the move away from fossil fuels to RE signals a broader and more profound response to global warming. Low-carbon energy is becoming more popular, and local pollution and climate change issues are interwoven; changes in the energy landscape will affect the relationships between producers and consumers [51,62]. Many European countries have enacted policies aiming to achieve carbon neutrality by 2050, which would have enormous economic, social, and political ramifications. The energy transition has already been recognised as one of the pillars of integrating an endurable energy supply within the Dutch government. They are committed to changing the energy, transportation, and agricultural systems for sustainable development. Discourse and change have been launched, using a transition management paradigm to achieve 'transitions' [63]. Considering this, Barbir, F. [10] highlighted that an energy system based on RE sources would be more sustainable as an alternative to fossil fuel-based electricity and hydrogen systems. Whether a country relies on fossil fuel reserves or access to nuclear energy, RE is likely to provide the best opportunity to achieve energy independence and self-sufficiency, regardless of a country's endowment in fossil fuel resources [64].

As a result of the Russian armed conflict, the energy performance of our selected eight EU countries is at risk. The majority of them rely on Russian energy. Nonetheless, the EU must also decarbonise its energy system and manage energy performance to achieve climate neutrality. Figure 4 illustrates how energy security and carbon neutrality can be achieved by applying three fundamental approaches. As a result of the combination of these three components, anthropogenic carbon emissions are offset to a significant extent. The combined implementation of these three components can also lead to carbon neutrality and energy security. First and foremost, the EU needs to diversify the energy supply by putting energy efficiency and RE sources at the top of the priority list. It also complies with the availability and accessibility of energy [13]. EU countries can withstand the use of fossil fuels, such as coal, oil, and natural gas, if they make use of diverse energy sources, including nuclear, solar, wind, and hydrogen energy. As we illustrated in the first component of our illustration, diversifying the energy supply can guarantee energy availability and accessibility. Second, the EU must invest in renewable and clean energy technology, improving energy efficiency and ensuring a reliable and inexpensive energy supply [14]. The second component of our illustration shows that investing in clean energy sources, such as solar, wind, and thermal energy, is necessary to ensure that everyone has access to inexpensive energy. At this particular time, fossil fuel prices are rising, due to the conflict in Ukraine, which has crippled the impoverished countries that import energy. Renewable energy sources can assist countries in mitigating climate change, building resilience to volatile price fluctuations, and lowering energy costs. Third, EU people must avoid energy waste and save energy to ensure energy supply stability and environmental sustainability [16]. The final part of our illustration describes an intense relationship between energy savings and environmental sustainability. Making a deliberate choice to consume less energy is known as energy conservation. By using less energy, people can slow down the depletion of fossil fuels and contribute to environmental clean-up. The EU needs to avoid energy waste and emphasise energy conservation as a sustainable strategy for bringing stability and sustainability to the environment.

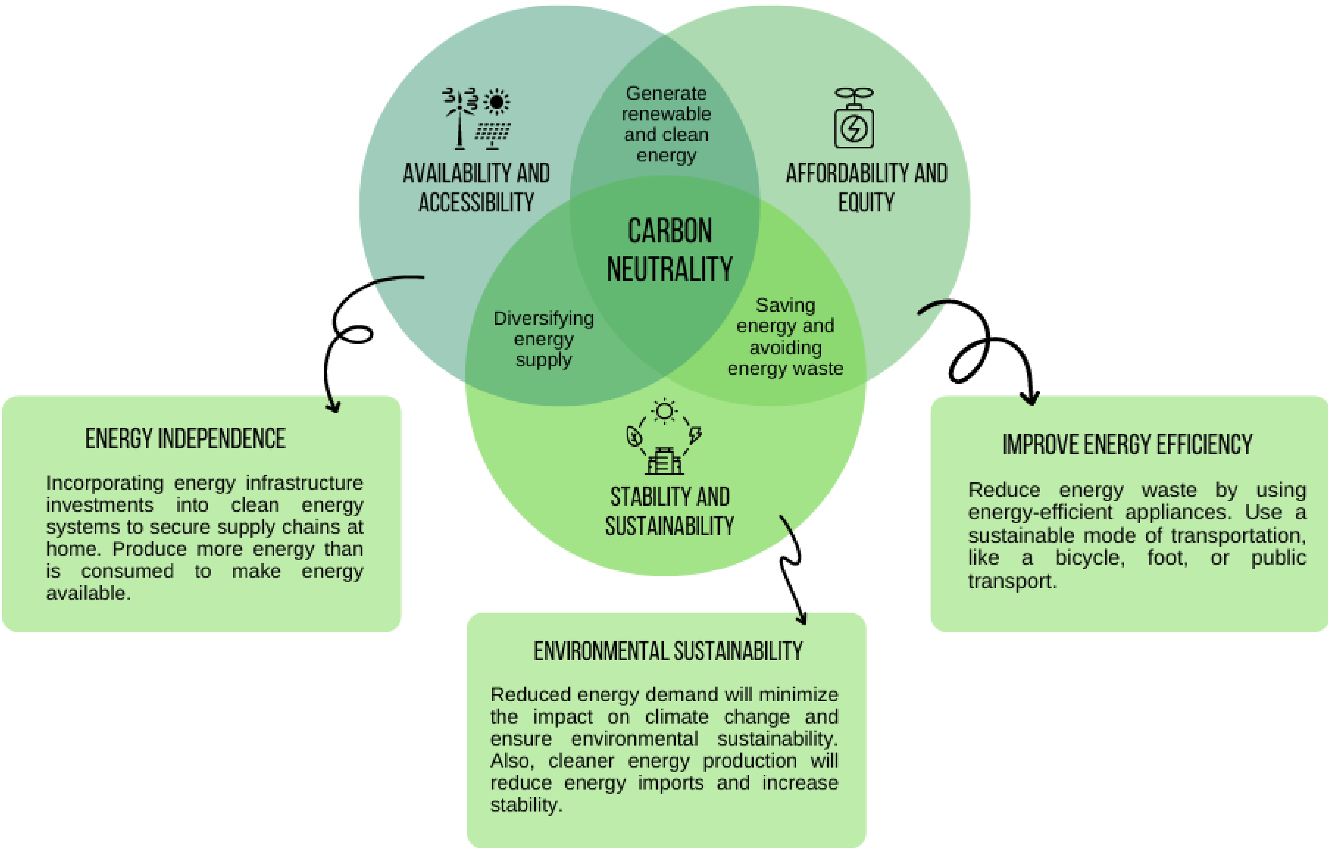


**Figure 4.** The energy transition towards carbon neutrality. Source: Developed by Authors, based on energy security pillars and RePowerEu plan.

In order to achieve carbon neutrality and energy security, further strategies are needed. A number of strategies are required to reduce emissions in the production and building sectors, such as the use of renewable energy, shifting fuel, and the utilisation of efficient technologies. Additionally, building sector management needs to be optimised to increase energy efficiency, reduce emissions cost-effectively, and achieve carbon neutrality. Technological advancements can help to achieve this goal [65,66]. In addition, the EU energy market needs to be integrated, networked, and digitalised [67].

In contrast, there are also concerns that RE may not be as reliable as those using fossil fuels heavily. Because RE systems are still in their infancy, fundamental uncertainties and accurate solutions exist. Further, citizens lack adequate knowledge and information about renewable energies and their long-term advantages. Ten strategies and policies are suggested to ensure the future RE transition in the CEU. These policies and strategies align with the Energy Union agenda, which was endorsed in 2015 [48]. In addition, these proposed policies and methods will assist the CEU countries in overcoming four significant challenges, i.e., fossil fuel shortage, environmental degradation, energy security, and the transition, to RE to fulfil future demands.

First, CEU citizens and industries should be educated and informed. Having a wide range of stakeholders involved is crucial to the long-term success of the RE strategy. A proactive approach to educating and informing the public and the business community helps build public acceptance and support. Because local opposition to energy infrastructure can pose significant barriers to achieving 100% RE and carbon neutrality, policymakers must educate citizens, foster engagement, and improve public outreach.

Second, transitioning to "zero-carbon" necessitates prudent comprehensive and long-term planning. Transition technologies, such as improving the efficiency of existing fossil fuel-based energy systems and switching from coal-powered energy to natural gas, can help reduce $CO_2$ intensity. Despite being a fossil fuel, natural gas emits 50–60% less $CO_2$ than coal-based energy power and can be used to offset the variability of solar and $CO_2$ power [68]. The EU needs to develop a roadmap with three milestones and timelines for achieving net-zero emissions: reducing the $CO_2$ intensity from GDP, minimising overall $CO_2$ emissions, and achieving carbon neutrality [69].

Third, annual RE investments must triple to USD 800 billion by 2050, from around USD 300 billion in recent years, to meet necessary global decarbonisation and climate goals [70]. The EU Commission recognizes the need to entice private investors to fund low-carbon initiatives; sustainable investments must be made appealing. Encouraging actors to establish and fund "green" ventures entails translating environmental benefits into monetary terms [71]. Investing in research and innovation, as well as transmission, are essential for a development sustainability transition. According to IRENA [72], 90% of RE projects were privately funded in 2016. As risks diminish and technologies develop, private investment is projected to have a greater share in future estimates.

Fourth, assign a high priority to energy efficiency. Prioritising energy efficiency is a fundamental step toward a sustainable energy future. Investing in more efficient energy infrastructure allows countries to construct, develop, and integrate the required infrastructure to meet their energy demands with locally accessible RE sources. Thus, it may be possible to decouple economic growth from greenhouse gas emissions growth and lower total investment requirements, while supporting economic growth decoupled from greenhouse gas emissions.

Fifth, make RE readily available to meet variable energy demands during all seasons. A diverse portfolio of RE sources will provide a more secure energy system than energy storage technologies alone.

Sixth, the selected EU countries analyzed the heating/cooling industry, and the transportation sector should be electrified. In the coming decades, governments should prioritise the transition of the heating and transportation sectors to a greater reliance on electricity. Integrating the electricity, heating/cooling, and transportation sectors is vital to reaching 100% RE, so renewable electricity can be deployed in various dispatchable uses, such as for thermal systems and charging electric vehicles [73].

Seventh, as energy systems transition from highly integrated and centralised complex networks to decentralised and local smaller frameworks that optimise supply, demand, and control by enabling efficient energy supply options at the household scale, they will be less vulnerable to potential power shortages [74]. Energy systems' ability to handle unexpected circumstances, minimise their impacts, respond quickly to their consequences, swiftly recuperate, and restore power can all be improved with digital technologies.

Eighth, regional cooperation among the analysed EU countries effectively ensures the European integrity of energy systems. A standard grid must connect eight EU countries to transfer RE. At the national level, energy interconnection can only be achieved incrementally.

In each selected EU member state, the construction of national grids and interregional connections should be followed by community-based microgrids.

Ninth, researchers need to conduct more research in this field to minimise concerns about future risks posed by some renewable energies.

Tenth, the EU countries analysed must increase RE and safe nuclear energy in their national energy portfolio to mitigate climate change and its consequences. It incorporates the concepts of usability, adaptability, and accessibility of RE to encourage citizens' energy-efficient behaviour.

Implementing these suggestions would address the viability of RE sources and the Sustainable Development Goals, such as SDG-7 (affordable and clean energy) and SDG-13 (climate action). In addition to fighting climate change in the selected CEU member states, these initiatives aim to make modern energy accessible, reliable, and sustainable across Europe.

## 6. Conclusions

Sustainable energy sources are a way to combat climate change, increase economic growth, increase access to energy, and reduce negative environmental and health effects [75]. RE directly impacts sustainable development through economic growth and human development. However, energy security goals differ based on a country's position in the energy market. Energy producer/exporter nations, such as Russia, Iraq, and the USA, aim to secure steady demand for their products to the EU; consumer nations, such as EU countries, want to diversify their energy demand to minimise import dependence and maximise security. As part of REPowerEU's effort to reduce Russian fossil fuel dependence, it aims to accelerate a clean transition and cooperate to create a more robust energy market [38].

The policy pathways required to convert the eight EU countries will differ in every country, with the most critical aspect being the determination of the people and government within every nation to effect swift transformation. This article makes no recommendations for specific policy changes in any country. Instead, it gives each country a range of policy options to explore. Many stakeholders have correctly underlined the importance of properly managing a "socially just" transition to guarantee affordable energy services for everyone, particularly the most deprived, while pursuing the necessary energy transition [76]. In addition to having "secure" energy supply chains, the transition must provide quality benefits for individuals' everyday lives, monetary action, and government services. Political influence must not compromise a low-carbon transition to carbon neutrality achievement targets.

The study identified several crucial energy transition trends affecting EU countries in favourable and unfavourable ways.

i. EU greenhouse gas (GHG) emissions fell by 31% in 2020, compared to 1990, indicating that the EU is on the right track to meet its carbon neutrality targets.
ii. RE has surpassed fossil fuels, bringing the EU closer to achieving 100% RE by 2050.
iii. The EU's overall energy import dependency climbed to 60.6%, potentially risking its energy security.
iv. Rising energy costs made it challenging to cope with the energy affordability dimension.
v. The EU must enhance energy efficiency and diversify renewable energy sources to ensure the availability and accessibility of energy, while maintaining carbon neutrality.
vi. A reliable and inexpensive energy supply can be ensured by investing in energy-efficient technology.
vii. Sustainable energy supplies and environmental sustainability can be achieved by reducing energy consumption and energy waste.

Nevertheless, the force of geopolitics and the Russian and Ukrainian war on energy security will shrink as RE sources are integrated into the energy mix over the remainder of the century. Furthermore, the energy-producing industry will comply with accessibility and acceptability targets for energy security and integrity.

The study concludes that, in EU countries, achieving carbon neutrality and energy sustainability through energy transition is strategically and economically viable through searching for alternative sources of clean energy supply, saving energy, generating renewable energies, and incorporating a circular and sustainable bioeconomy.

However, energy import dependency, rising costs, political challenges around RE, armed conflicts, and partial carbon emission reduction policies remain significant hurdles. Further research is needed to overcome those issues.

Some limitations are present in this paper. Russia's current energy strategy with Europe is to test Europe's ability to withstand an energy crisis this winter. If the EU can maintain solidarity and effectively coordinate this winter, it will have a more substantial long-term position concerning Russia. This crisis will force a significant rethink of the EU's energy and gas security over the next decade, including the diversification of outside sources of gas (Africa and the Americas) and the increasing gas exchanges within the EU member states, ensuring higher gas stocks.

Several member states of the EU are enacting wide-ranging, energy-saving measures to help curb electricity and natural gas use. In addition, consumers are stockpiling wood for the upcoming winter. The expected economic recession and increasing gas and electricity prices will hit consumers hard, leading to further government intervention. Given that we are unsure of the severity of the EU's energy issue, the only question is how much worse things will get. Even EU-wide price caps are among the potential plans in the EU.

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