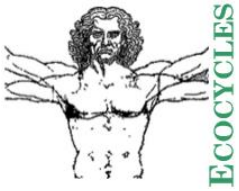
ECOCYCLES
ISSN 2416-2140

OPEN ACCESS
Scientific journal of the
European Ecocycles Society



Ecocycles, Vol. 9, No. 2, pp. 7-25 (2023)
DOI: 10.19040/ecocycles.v9i2.285

RESEARCH ARTICLE

Assessing waste management efficiency in the European Union: A focus on the Slovak Republic

Marina Valenćiková[1] and Peter Fandel[2]

[1,2] *Slovak University of Agriculture in Nitra, Faculty of European Studies and Regional Development, Institute of Law, Nitra 949 76, Slovakia,*

Corresponding author: Marina Valenćiková, Ing. email: xvalencikova@uniag.sk

Abstract – Even though every country in the EU must follow the waste management hierarchy stipulated in Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste, there are differences in how the member states manage their municipal waste. For example, the percentage of recyclable and incineration with energy recovery of municipal waste is among the lowest in the Slovak Republic (and the high amount of its disposal by landfilling). However, following the European Union legislation, several strategies in the Slovak Republic, such as the Waste Prevention Program 2019-2025, Waste Management Program 2021-2025, and Envirostrategy 2030, have been adopted. Based on these strategies, the recycling rate is scheduled to increase to 65% by 2035, and the percentage of municipal waste sent to landfills is planned to fall below 25%. These projections assume the successful implementation of the programs. As a result, the Slovak Republic's waste is significantly lower than that of other member states. When investigating the efficiency of municipal waste management, we utilised partial treatment-specific indicators and a composite indicator based on an approach known as the multi-criteria decision-making method. The highest efficiency of municipal waste management in the EU-27 in 2021, expressed by the composite indicator, was achieved by Germany (0.630), and the lowest performance by Malta (0.188). For the evaluated period of 2017–2021, municipal waste management efficiency improved the most in Malta (+28.4%) and deteriorated the most in Denmark (-20.8%). The broader implications of our research have shown significant differences in partial treatment-specific indicators across the EU-27.

Keywords – municipal waste treatment efficiency, waste management hierarchy, environmental strategies, EU-27, legislation

Received: March 18, 2023 Accepted: April 24, 2023

INTRODUCTION TO THE WASTE MANAGEMENT AND CIRCULAR ECONOMY

Waste management efficiency is evolving into a factor that is gaining increasing significance (Yu *et al.*, 2022; Liang *et al.*, 2021). Furthermore, according to the *World Scientists' Warning to Humanity* findings, Ripple *et al.* (2017) stated that humankind is getting dangerously close to several of the planet's boundaries. These boundaries include the planet's capacity for absorbing waste, providing food and energy, and increasing its population. The global population has proliferated, especially in the last century (Cherubini *et al.*, 2009; Khan *et al.*, 2021). At the beginning of the 20th century, the global population was approximately 1.65 billion individuals. Moreover, the global population is estimated to hit 8.05 billion by 2023 by Our World in Data (2023). In other words, the day the world's population hit 8 billion, November 15, 2022, was a milestone in human development (United Nations, 2022).

Equally important, increased consumerism (Van Kerckhove, 2012; Dini, 2016), elevated innovation (Maradana *et al.*, 2019), and a linear approach to industrialisation (Ginga *et al.*, 2020) have all contributed to an increase in the severity of the waste problem in the 21st century. Following that, the society of the 20th and 21st centuries is known as the *Society of Waste* since it is a wasteful consumer of large quantities of water, materials, and energy resulting from a social metabolism based on non-renewable resources and is not ecologically sustainable (Knorr and Augustin, 2022; Marín-Beltrán *et al.*, 2022).

Consequently, waste reduces material flow throughout society, like managing resources. Most material flows in the modern world are linear, moving from the point of origin to the landfill. Under those circumstances, people should get better at managing waste to increase the cyclical nature of material flow and reduce the amount of material they consume before achieving sustainability (Zbicinski *et al.*, 2006; Rusch *et al.*, 2022; Spišáková *et al.*, 2022). With this in mind, circularity is vital to a more significant shift in the industry toward being climate neutral and staying competitive in the long run. The circular economy (CE) can make getting and using resources much more manageable without damaging the environment. Another critical point is that it can also help restore biodiversity (Velenturf and Purnell, 2021; Stanescu, 2021). The CE is essential because its primary goal is reducing waste. Upon reaching the end of its life cycle, efforts are made to retain the materials of a product within the economy to the extent feasible. These items can be repeatedly utilised productively, resulting in the generation of additional value. Implementing measures aimed at achieving a CE involves:

- Adopting practices such as reusing.
- Repairing and refurbishing.
- Recycling pre-existing materials and products.

The transformation of what was previously deemed as refuse into a valuable commodity is now a recognised possibility. Numerous instances exist of corporations applying the notion to particular goods across diverse industries (European Parliament, 2016). The research on Life Cycle Assessment (LCA) has been centred on the subject of waste comprehensively, encompassing diverse materials such as paper and metals, as well as specific products. The waste investigation bears considerable significance for local governments, given their customary responsibility for its administration. Examining specific materials can aid in assessing diverse alternatives, such as energy production via incineration and the manufacture of fuel through plastic processing (Zbicinski, 2006).

It is imperative to consider the economic competition when evaluating the CE. Also, the CE focuses on reducing the environmental effects of production and consumption (Pires and Martinho, 2019; Smol *et al.*, 2020). Furthermore, managing municipal waste (MW) has long been a substantial issue in cities. As a result, the European Commission has exerted great effort to devise the most efficient waste management strategies, particularly as the world moves toward a CE (Banias *et al.*, 2020). In a linear economy, goods are utilised until they are no longer helpful (MacArthur, 2013). On the negative side, CE's concept is criticised since circularity has over a hundred different definitions, so it has different meanings for others. Immediately, it is only sometimes visibly evident that circularity and sustainability are interconnected (Kirchherr *et al.*, 2017). Weigend Rodríguez *et al.* (2020) and Corvellec *et al.* (2022) implied that the efficiency of CE practices in promoting environmental and social sustainability remains unclear, leaving the future open to a variety of potential possibilities.

In the meantime, the principles of CE are not orientated around the management of material and waste streams but focused on more efficient practices, including maintenance, reuse, and recycling (Khomenko *et al.*, 2021). Eurostat (2023) reported that EU-27 countries generate an average of 530 kilograms of waste per person per year, making the increase in waste production a severe issue.

In general, the EU-27 in 2021 produced 236,801 thousand tons of waste. In 2017, the average generated waste per capita in the EU-27 was 49.9%. Luxembourg had the highest waste production rate of 79.3% in 2021. Waste production in Belgium experienced a significant increase from 41.6% in 2019 to 72.9% in 2020. Denmark exhibits a notable per capita waste generation rate, albeit with a decreasing trajectory. Regarding municipal waste generation, Romania is the country with the lowest production.

Nevertheless, it is worth noting that this trend has been on the rise in recent years. Specifically, while the percentage of municipal waste generated in Romania was 27.2% in 2017, it increased to 30.2% in 2021. Poland and Estonia are among the countries that generate the lowest amount of waste. The Slovak Republic (SR) is situated in the middle, is ongoing, and tends to expand.

This study aims to analyse the impact of the regulatory strategies on the municipal waste management efficiency of SR in comparison with EU-27 countries in the years 2017-2021. The efficiency study is primarily grounded in a theoretical framework constructed through the examination of Environment Strategy 2030 - Greener Slovakia (Envirostrategy, 2030), Waste Management Program 2021-2025 (WMP), and Waste Prevention Program 2019-2025 (WPP).

METHODOLOGY AND DATA

In analysing municipal waste management efficiency, we employed partial treatment-specific indicators and a composite indicator based on the multi-criteria decision-making (MCDM) approach. The selected partial indicators represent the most critical municipal waste treatment methods reflecting waste management hierarchy as follows: the generated municipal waste per capita and volumes of treated waste per capita (recycling-material, recycling-composting and digestion, disposal-incineration with energy recovery, and disposal-landfill).

The composite indicator is a single score or rank that reflects the overall performance of evaluated units, considering multiple aspects or indicators. In the study, we employ a straightforward Weighted Sum Method (WSM) (Churchman and Ackoff, 1954).

Waste management efficiency problem as an MCDM problem is expressed in the decision matrix in Table 1:

Table 1. Decision matrix for the waste management performance MCDM problem

Criteria:	(WM treatment methods)	C_1	C_2	..	C_j	..	C_n
Weights:	(Treatment methods hierarchy)	w_1	w_2	..	w_1	..	w_1
Alternatives:	A_1	x_{11}	x_{12}	..	x_{1j}	..	x_{1n}
(EU countries)	A_2	x_{21}	x_{21}	..	x_{2j}	..	x_{2n}
	:	:	:	..	:	..	:
	A_i	x_{i1}	x_{i2}	..	x_{ij}	..	x_{in}
	:	:	:	..	:	..	:
	A_m	x_{m1}	x_{m2}	..	x_{mj}	..	x_{mn}

A decision matrix is an $(m \times n)$ matrix where x_{ij} is the quantity per capita (kg) for the country A_i and the WM treatment method C_j. Numerical weight w_j assigned to each criterion expresses its importance. Symbol n represents the number of criteria and m is the number of countries under evaluation.
In our analysis, we use the following five criteria:
C_1 municipal waste generated (kg per capita) – minimisation criterion.
C_2 recycling-material (kg per capita) – maximisation criterion.
C_3 recycling- composting and digestion (kg per capita) – maximisation criterion.
C_4 disposal - incineration with energy recovery (kg per capita) – maximisation criterion.
C_5 disposal-landfill (kg per capita) – minimisation criterion.

The rank reflects of criteria reflects Directive (EU) 2018/851, article 4, on waste hierarchy in descending order. The hierarchy is translated into weights employing Rank Sum Weight (RSW) method. In the RSW, the weights assigned to each criterion are calculated by dividing the rank of each criterion by the sum of the ranks. Specifically, the weight for each criterion is calculated as (Stillwell *et al.*, 1981):

$$w_j = \frac{n - r_j + 1}{\sum_{k=1}^{n} n - r_k + 1} = \frac{2(n+1-r_j)}{n(n+1)} \quad \text{Eq. (1)}$$

where r_j is the rank of the jth criterion, $j = 1, 2,..., n$.
Resulting weights used in our study are: $w_1 = 0.333$, $w_2 = 0.267$, $w_3 = 0.200$, $w_4 = 0.133$, $w_{j5} = 0.067$.

To work with the single (or unified) type of criteria, values of minimisation criteria C_1 and C_5 were transformed to maximisation ones using the following formula:

$$\hat{x}_{ij} = (\, max_i(x_{ij}) - x_{ij}),\ i = 1, 2, \ldots, m;\ j = 1, \text{and } 5. \quad \text{Eq. (2)}$$

The expression (3) gives the WSM composite indicator of waste management efficiency for the ith country:

$$E_i = \sum_j a_{ij}\ w_{ij}, \quad \text{Eq. (3)}$$

where E_i is the Weighted Sum Method efficiency score for the alternative A_i and a_{ij} is the normalised value of x_{ij}. The formula for the normalisation of x_{ij} is as follows:

$$a_{ij} = (x_{ij} - min_i(x_{ij}))/(\, max_i(x_{ij}) - min_i(x_{ij})),\ a_{ij} \in < 0; 1 > \quad \text{Eq. (4)}$$

The maximum value of E_i indicates the best-performing country:

$$E^*_{wsm} = max_i\,(E_i),\ E_i \in < 0; 1 > \quad \text{Eq. (5)}$$

The analysis utilised data from the *Eurostat database "Municipal waste by waste management operations (*env_wasmun*)", published on October 14, 2022*, representing years 2017-2021.

RESULTS

Markedly a package of policy initiatives, the European Green Deal is an aspirational strategy concerning the EU-27 (Dobbs *et al.*, 2021). In other words, Europe's climate neutrality by 2050 requires rapid emission reductions under the European Green Deal. For this reason, it must reduce regional and social inequalities in Europe to gain support (Wolf *et al.*, 2021) As acknowledged by Fetting (2020), it wants more regulatory and non-regulatory information and measures to combat greenwashing. It is crucial to remember that the Circular Economy Action Plan aims to decouple resource utilisation from economic growth. Also, it is essential to recognise that the New Circular Action Plan, adopted in March 2020, seeks to reduce waste while limiting the use of packaging, batteries, construction materials, and food. Zhang *et al.* (2022) elucidated that the Waste Framework Directive 2008/98/EC adopted the waste management hierarchy principle in 2008. The European Union's member states were able to benefit from the implementation of the policy. It was applicable across the member states of the European Union. The waste management hierarchy, which suggests a priority order with prevention at the top and disposal at the bottom, significantly influences current waste management practices (Gharfalkar *et al.*, 2015).

Van Ewijk and Stegemann (2016) concluded that the waste management hierarchy was valuable in that it prevented waste from being disposed of in landfills, but on the contrary, insufficient in its capacity to reduce the consumption of natural resources and negative environmental impact. Directive 2008/98/EC of the European Parliament and of the Council of November 19, 2008, on waste and repealing

certain Directives (Framework Directive), requires each Member State to have WMP and WPP as essential waste management documents. Directive 2008/98/EC, which was then transposed into national law, set out the Waste Hierarchy by December 12, 2010. Competent federal authorities created WMPs and WPPs under this directive. As is demonstrated in Directive (EU) 2018/851, to meet the objectives of the waste management hierarchy Directive, the preparation of municipal waste for reuse and recycling must increase to a minimum of 55%, 60%, and 65% by weight by 2025, 2030, and 2035, respectively. Besides these targets, member states must collect textiles, hazardous waste, and bio-waste separately by January 1, 2025, and compost bio-waste by December 31, 2023. Also, by 2035, the Landfill Directive restricts the landfilling of municipal waste to 10%. (Directive 1999/31) The waste management hierarchy has not changed as a result of the adoption of Directive (EU) 2018/851 of the European Parliament and of the Council of the European Union on May 30, 2018, which amends Directive 2008/98/EC on Waste, and they remain unaffected:

1. Prevention of occurrence.
2. Preparation for reuse.
3. Recycling.
4. Other recovery, *e.g.*, energy recovery.
5. Disposal.

Taelman *et al*. (2018) asserted that a mandatory waste management hierarchy is the foundation of European waste law and policy. The primary goals of the waste management hierarchy are to increase and optimise waste management resource utilisation while minimising environmental impacts. According to De Feo *et al*. (2019), the primary function of waste management policies is, therefore, of fundamental importance.

In terms of current situation in SR, based on the legal basis of Regulation No. 365/2015 Coll. of establishing the Waste Catalogue as amended, Regulation No. 366/2015 Coll. on registration obligation and reporting obligation as amended, Regulation No. 371/2015 Coll. of implementing some provisions of the Waste Act as amended, Directive 2008/98/EC on Waste and Act No. 79/2015 § 80 Coll. on Waste *"Municipal waste is household waste generated on the territory of the municipality during the activities of natural persons and waste of similar characteristics and composition, the origin of which is a legal entity or a natural person - an entrepreneur, except for waste generated during the immediate performance of activities forming the subject of business or activities of a legal entity or a natural person - entrepreneur; waste from households is also considered waste from real estate used by natural persons for their individual recreation, for instance from gardens, cottages, or for parking or storing a vehicle used for household needs, especially from garages, garage spaces and parking spaces."*

In addition, the SR has implemented several environmental protection policies mandated by EU law. Envirostrategy 2030, the WMP for 2021-2025, and the WPP for 2019-2025 are the three most essential documents in SR that pertain to the municipal waste efficiency analysis. The WMP for 2021–2025 and WPP for 2019–2025 are important strategic documents requiring SR to divert as much waste as possible from landfills to other recycling methods and reduce the amount generated on its territory.

The primary objective of Slovak WMP until 2025 is to deflect municipal waste from landfills. The funding of municipal waste collection and disposal through the Extended Producer Responsibility (EPR) scheme, as well as the levying of charges on local municipal waste and small construction waste, is acknowledged. However, sorting municipal waste, specifically biodegradable waste such as kitchen waste, must be improved. Municipal waste receives the most attention, despite representing only a tiny portion of overall waste generation. This special attention is due to the public sector's collection and management of municipal waste. Marišová and Fandel (2022) stated that efforts are being made to recover waste in accordance with the Slovak strategies. Equally positive that the number of waste incineration plants in both regions (Košice and Nitra regions) under study tends to decrease.

The most significant waste stream regarding the origin, trends, infrastructure planning, and waste policy objectives is a municipal waste. Often overlooked, misinterpreting municipal waste can harm processing capacity planning and meeting European recycling and landfilling goals. Consequently, defining municipal waste consistently was one of the most significant obstacles in adopting the new waste package following the EU Action Plan for the CE. Therefore, we agree with Lazikova and Rumanovská (2022), who claimed that it is irrational, on the one hand, to inform the consumer of the basic knowledge which unnecessarily takes up space on the packaging of the food required by Regulation (EU) No. 1169/2011 of the European Parliament and of the Council of October 25, 2011, on the provision of food information to consumers.

On the other hand, the calculations indicate that biodegradable municipal waste is the most prevalent component of mixed municipal waste. Following the EU Green Deal also mandates a more efficient public administration in SR. Therefore, in February 2019, the SR adopted the Environmental Strategy 2030 after 26 years. Envirostrategy 2030 has three sections: the green economy section governing the CE, waste management, and energy plans. Concerning municipal waste, the CE core objectives of Envirostrategy 2030 are as follows:

- The rate of recycling municipal waste, including preparation for reuse, is expected to rise to 60% by the year 2030.
- By 2035, the percentage of municipal waste sent to landfills will drop 25% below.

Recent data from the Statistical Office of the SR for 2021 indicate a high percentage of municipal waste disposed of in landfills (40.68%). The annual decline in landfilling has been positive; for example, in 2011, up to 74.71% of municipal waste in SR was disposed of in landfills. Nevertheless, SR lags behind developed countries in waste management, where

in terms of recycling rates, municipal waste took 12th place out of 27 EU countries (2020: 42.2%), where the EU-27 average is 48.6%. While landfilling is still the dominant form of waste management, it took 12th place in 2020, and the recycling rate was 49.66%. However, SR produces much less waste than other Member States, with 496 kg per capita in 2021 or 1,077 thousand tonnes (EEA [(1),(2)]).

Regarding generated waste per capita, on EU-27 average in 2017 was 49.9%; however, it increased to 53%. The highest produced waste is in Luxembourg, at 79.3% in 2021. In comparison to 2017, this trend declined. In Belgium, a big jump in waste production was from 2019 (41.6%) to 72.9% in 2020. Denmark also has a high generation of waste per capita; however, this trend is declining. Regarding countries with the least municipal waste generation, Romania produces the least of it; however, this trend is increasing from year to year; in 2017, it was 27.2%; however, in 2021, it was 30.2%. Poland and Estonia are also the countries with the least waste. In terms of SR, there is a tendency for an increase in municipal waste production on an annual basis (Table 2).

Table 2. Municipal waste generated in EU-27 between 2017-2021 (kg per capita)

Criterium/Year	**2017**	**2018**	**2019**	**2020**	**2021**	**2021/2017**
EU-27	499	500	504	521	530	**106%**
Belgium	411	409	416	729	759	**185%**
Bulgaria	435	407	442	408	398	**91%**
Czechia	489	494	500	543	570	**117%**
Denmark	820	814	844	814	786	**96%**
Germany	627	606	609	641	646	**103%**
Estonia	390	405	369	383	395	**101%**
Ireland	576	598	625	644	647	**112%**
Greece	504	515	524	544	552	**109%**
Spain	473	475	472	464	472	**100%**
France	558	557	555	538	561	**101%**
Croatia	416	432	445	418	446	**107%**
Italy	488	499	503	487	516	**106%**
Cyprus	625	646	648	609	633	**101%**
Latvia	411	407	439	478	461	**112%**
Lithuania	455	464	472	483	480	**105%**
Luxembourg	798	803	791	790	793	**99%**
Hungary	385	381	387	403	416	**108%**
Malta	666	672	697	643	611	**92%**
Netherlands	513	511	508	533	515	**100%**
Austria	570	579	588	834	635	**111%**
Poland	315	329	336	346	362	**115%**
Portugal	486	507	513	513	514	**106%**
Romania	272	272	280	290	302	**111%**
Slovenia	471	486	504	487	511	**108%**
Slovakia	378	414	421	478	496	**131%**
Finland	510	551	566	611	609	**119%**
Sweden	452	434	449	431	418	**92%**

Figure 1 illustrates that the mean quantity of municipal waste generated per capita in the EU-27 in 2017 was 499 kg. In contrast, the total amount of municipal waste produced per capita in the SR in 2017 was 378 kg, making the SR one of the places within EU member states that produced the least waste. Nevertheless, when compared to 2017, SR had a waste generation rate that was 118 kg per capita higher, while the level for the EU-27 was 31 kg per capita higher. However, if recovered or recycled, this trend may not necessarily have a negative outcome.

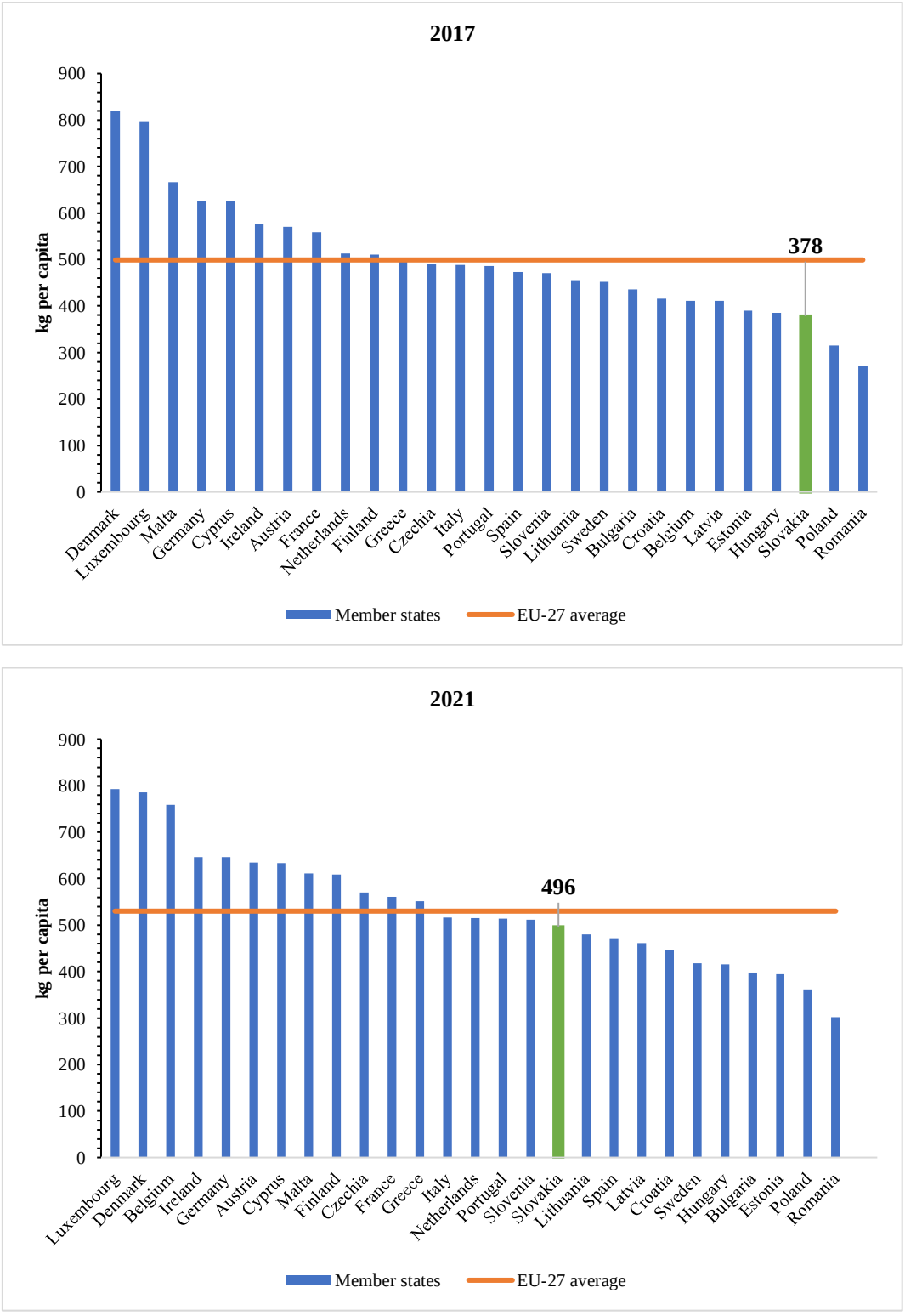


Figure 1. Municipal waste generated in EU-27 in 2017 and 2021 (kg per capita)

The second criterion, recycling-material, is illustrated in Table 3. When we compare 2017 and 2021 in the EU-27, the proportion of recycled municipal waste increased by 6.80% during the study period. Germany has the highest recycling rate, with 30.1% in 2021, but this trend was lower in 2017. Denmark experienced the sharpest decline, with material recycling rates falling from 30.7% in 2017 to 9.2% in 2021. Regarding SR, material recycling rates increased by 106.25% compared to 2017. On the other hand, the least recycling-material is seen in Romania (2021: 2%).

Table 3. Recycling-material in EU-27 between 2017-2021 (kg per capita)

Criterium/Year	**2017**	**2018**	**2019**	**2020**	**2021**	**2021/2017**
EU-27	147	147	150	154	157	**107%**
Belgium	140	141	142	235	237	**169%**
Bulgaria	117	121	119	19	120	**103%**
Czechia	107	109	110	150	175	**164%**
Denmark	236	263	283	208	92	**39%**
Germany	307	298	292	300	301	**98%**
Estonia	96	98	104	100	107	**111%**
Ireland	181	175	174	190	243	**134%**
Greece	74	77	84	86	89	**120%**
Spain	87	86	93	95	90	**103%**
France	122	119	121	126	142	**116%**
Croatia	89	97	119	102	118	**133%**
Italy	136	144	151	135	159	**117%**
Cyprus	92	97	97	93	87	**95%**
Latvia	73	78	158	155	167	**229%**
Lithuania	110	113	130	118	126	**115%**
Luxembourg	237	239	235	232	238	**100%**
Hungary	103	111	103	90	106	**103%**
Malta	77	70	63	70	82	**106%**
Netherlands	136	139	141	148	144	**106%**
Austria	147	147	154	337	188	**128%**
Poland	84	86	84	92	98	**117%**
Portugal	59	62	62	65	70	**119%**
Romania	20	21	20	16	20	**100%**
Slovenia	199	207	214	219	234	**118%**
Slovakia	80	111	113	148	165	**206%**
Finland	140	161	166	177	150	**107%**
Sweden	142	130	146	87	83	**58%**

Figure 2 shows that the average amount of recycled material per capita across the EU-27 in 2017 was 147 kg. In contrast, the amount of recycling material per capita in the SR in 2017 was 80 kg, placing the SR in the lowest places across the EU-27. However, the situation changed significantly in 2021, when recycling material was produced at a rate of 165 kg per capita in the SR, whereas the average for the EU-27 was 157 kg per capita, this meant that the SR's rate was higher than the EU-27's rate and that it was places ninth out of the 27 member states.

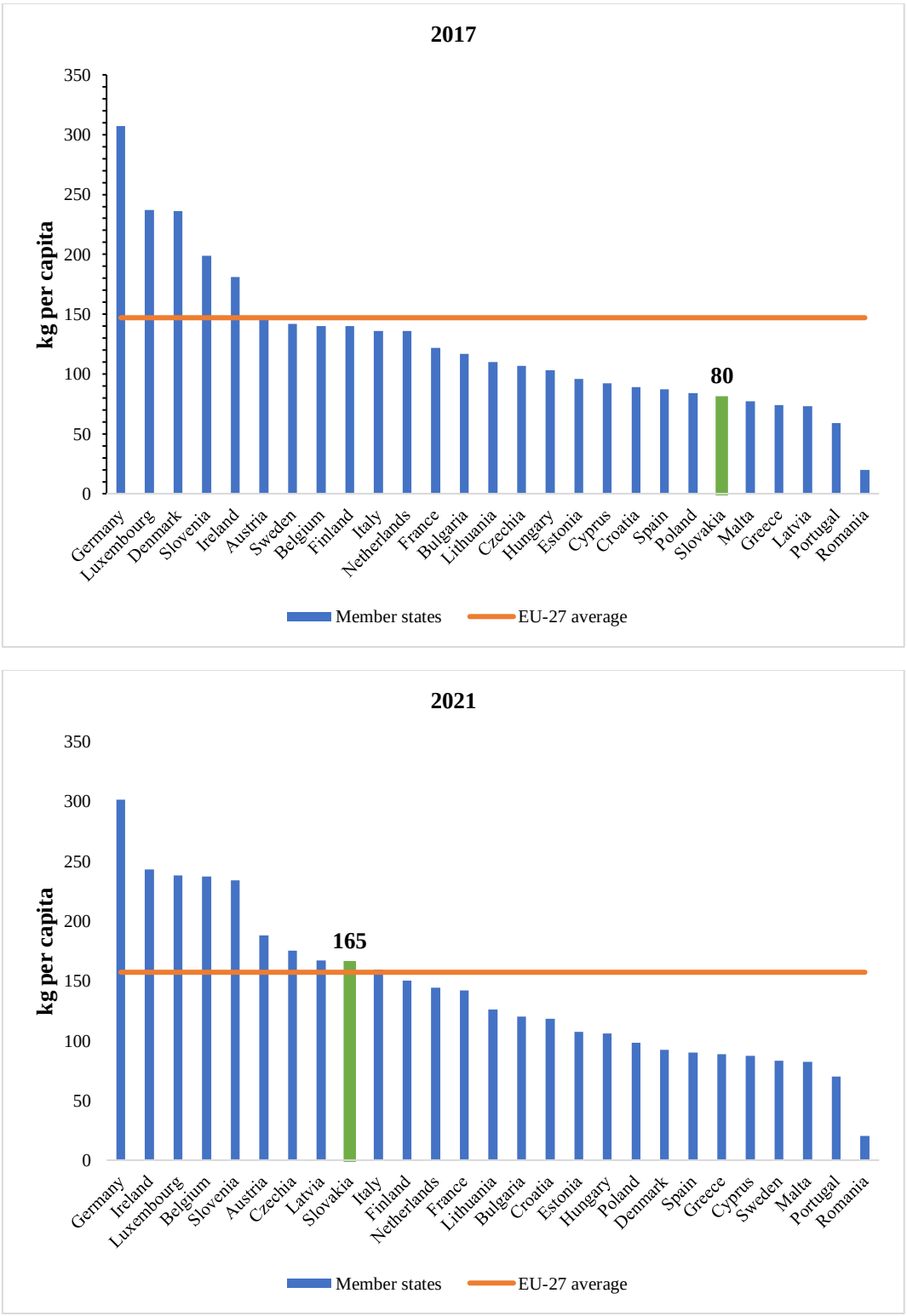


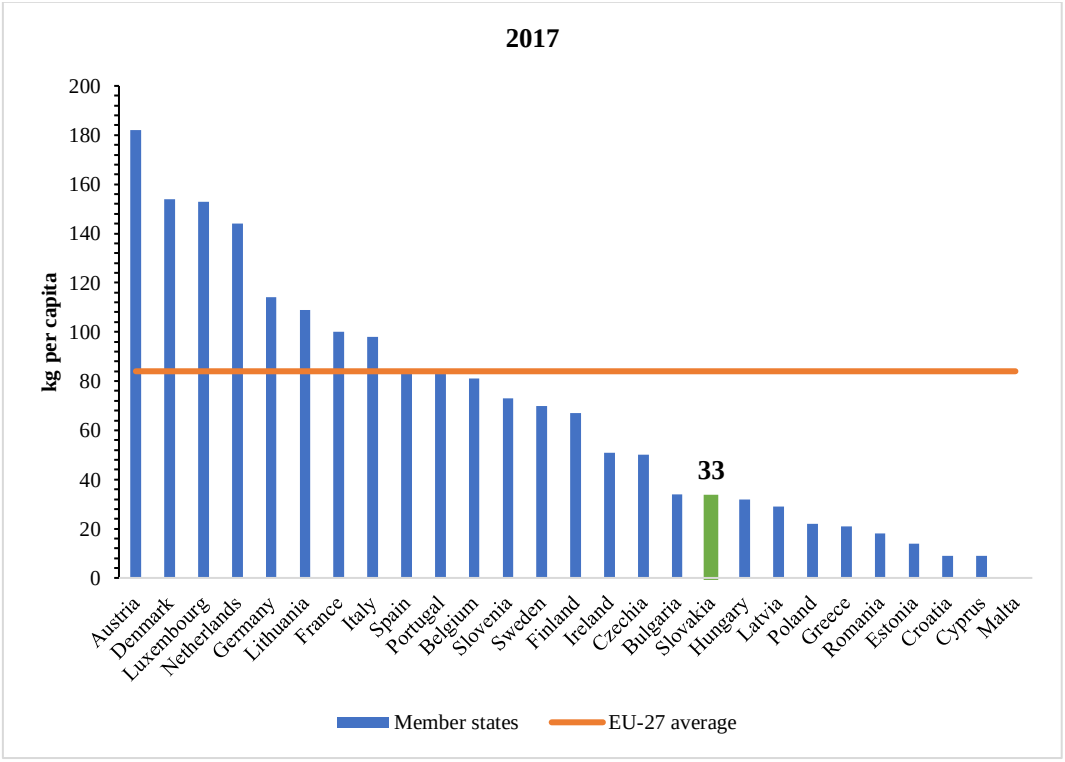
Figure 2. Recycling-material in EU-27 in 2017 and 2021 (kg per capita)

Table 4 illustrates recycling – composting, and digestion, where this trend continues to grow on the EU-27 level in investigated period. In the prominent position is Luxembourg, where in 2017, the percentage point of recycling - composting and digestion was 15.3%; however, it rose to 20% in 2021. A similar trend of increase is in Denmark, Germany, and Belgium. In Austria in 2017, the recycling rate was 18.2%; however, in 2021, it decreased by 0.2%. Malta does not implement recycling – composting and digestion with 0%. Nevertheless, SR has made enviable progress.

Table 4. Recycling-composting and digestion in EU-27 between 2017-2021 (kg per capita)

Criterium/Year	**2017**	**2018**	**2019**	**2020**	**2021**	**2021/2017**
EU-27	84	84	87	97	100	**119%**
Belgium	81	82	86	137	163	**201%**
Bulgaria	34	7	34	5	24	**70%**
Czechia	50	50	56	70	73	**146%**
Denmark	154	143	152	158	178	**116%**
Germany	114	109	114	143	150	**132%**
Estonia	14	15	9	10	13	**93%**
Ireland	51	50	60	70	61	**119%**
Greece	21	26	26	23	24	**113%**
Spain	84	80	86	93	83	**99%**
France	100	106	104	97	108	**108%**
Croatia	9	12	15	21	22	**244%**
Italy	98	105	107	116	113	**116%**
Cyprus	9	11	9	6	8	**89%**
Latvia	29	25	22	35	37	**128%**
Lithuania	109	131	105	100	86	**79%**
Luxembourg	153	154	152	186	200	**131%**
Hungary	32	32	36	39	39	**122%**
Malta	0	0	0	0	0	**0%**
Netherlands	144	147	148	156	154	**107%**
Austria	182	187	189	179	180	**99%**
Poland	22	27	30	42	48	**218%**
Portugal	83	86	86	72	86	**104%**
Romania	18	9	12	18	14	**78%**
Slovenia	73	79	84	70	72	**99%**
Slovakia	33	39	49	65	77	**233%**
Finland	67	72	80	80	76	**113%**
Sweden	70	69	64	78	82	**117%**

If recycling-composting and digestion are compared, the average for the EU-27 was 84 kg per capita in 2017 and 100 kg in 2021. For instance, Austria was in first place with 182 kg per capita and remained slightly fluctuating throughout the study. Following closely in its footsteps are Denmark and Luxembourg. SR has made more progress since 2017 and is now in the middle of the member states in terms of success. However, it still needs to catch up to the EU-27 average of 100 kg per capita in 2021 and has yet to make much progress since 2017 (Figure 3).



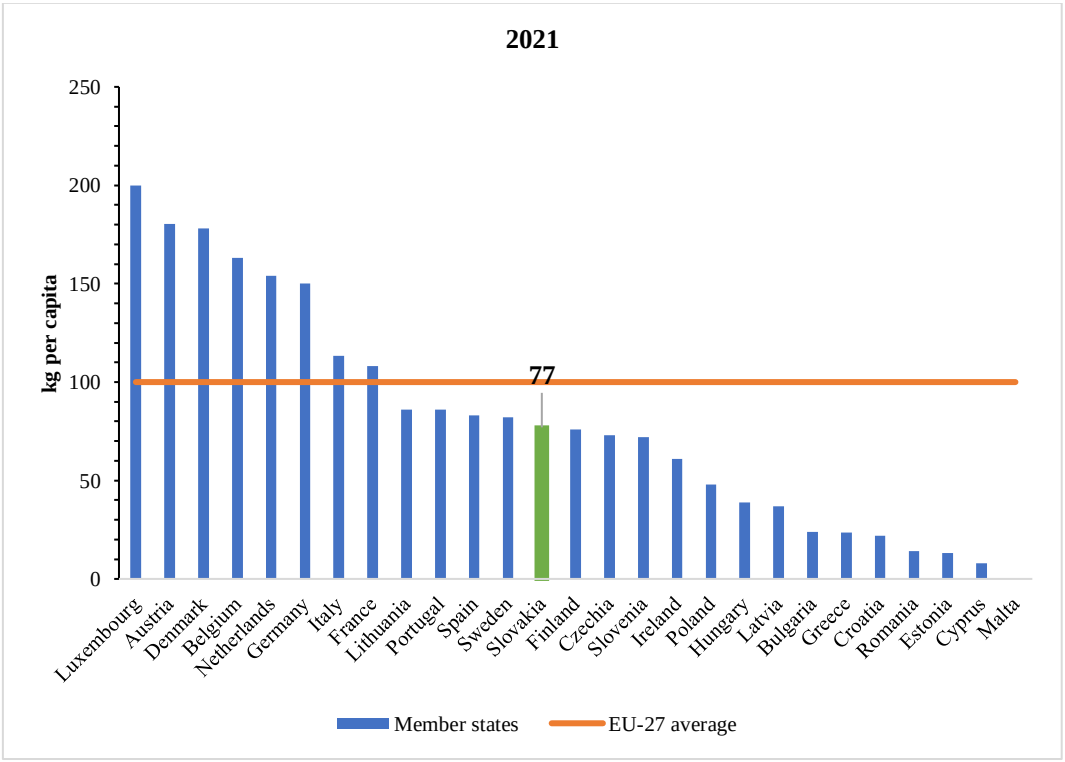


Figure 3. Recycling-composting and digestion in EU-27 in 2017 and 2021 (kg per capita)

Table 5 shows significant progress in most countries regarding incineration with energy recovery, particularly in Denmark (2021: 53.9%), Finland (2021: 38.1%), Sweden (2021: 24.9%), and Luxembourg (2021: 32.3%). However, European legislation in energy recovery support distinguishes between countries that have already built sufficient infrastructure, *e.g.*, Denmark or Germany, and countries still dependent on landfilling, such as SR, *i.e.*, precisely following the waste management hierarchy. Furthermore, it underlines the need to adequately size the new potential for energy retrieval from refuse. SR is progressing; in 2017, the disposal – incineration with energy recovery was 3.6%, but in 2021, it was 4%.

Table 5. Disposal-incineration with energy recovery in EU-27 between 2017-2021 (kg per capita)

Criterium/Year	**2017**	**2018**	**2019**	**2020**	**2021**	**2021/2017**
EU-27	131	131	131	143	146	**112%**
Belgium	176	177	178	356	368	**209%**
Bulgaria	15	30	15	0	12	**82%**
Czechia	85	83	82	69	69	**81%**
Denmark	421	397	401	435	539	**128%**
Germany	200	195	198	194	193	**97%**
Estonia	165	167	167	164	192	**116%**
Ireland	183	255	286	271	222	**121%**
Greece	5	8	7	5	6	**110%**
Spain	60	55	52	61	62	**103%**
France	174	173	171	173	175	**101%**
Croatia	0	0	0	1	1	**0%**
Italy	93	95	99	94	115	**124%**
Cyprus	2	5	6	9	15	**750%**
Latvia	11	8	15	13	10	**89%**
Lithuania	83	58	70	125	169	**204%**
Luxembourg	372	375	369	341	323	**87%**
Hungary	62	51	53	48	52	**84%**
Malta	0	0	0	0	25	**0%**
Netherlands	226	218	212	222	211	**93%**
Austria	221	224	226	299	236	**107%**
Poland	77	79	77	74	76	**99%**
Portugal	96	92	97	110	125	**131%**
Romania	12	12	13	15	18	**150%**
Slovenia	54	50	66	64	56	**104%**
Slovakia	36	34	39	35	40	**111%**
Finland	299	314	314	350	381	**127%**
Sweden	239	232	236	259	249	**104%**

If we examine Figure 4, which compares 2017 and 2018 regarding incineration with energy recovery for the entire EU-27, we can observe that Denmark is increasing its recovery in both years. In countries with limited primary resources, such as Denmark, the slag utilisation rate is significantly higher than in countries with unlimited primary resources. It brings us back to the core concepts underlying the CE, which include increasing the time materials are in circulation and decreasing the number of materials produced in the first stage. The quality of the slag is not the decisive factor in its usability; instead, the construction industry's compliance with CE regulations ultimately determines its employability. Because the average for EU-27 in 2017 was 131 kg per capita and the average for EU-27 in 2021 is 146 kg per capita, EU-27 has improved its position.

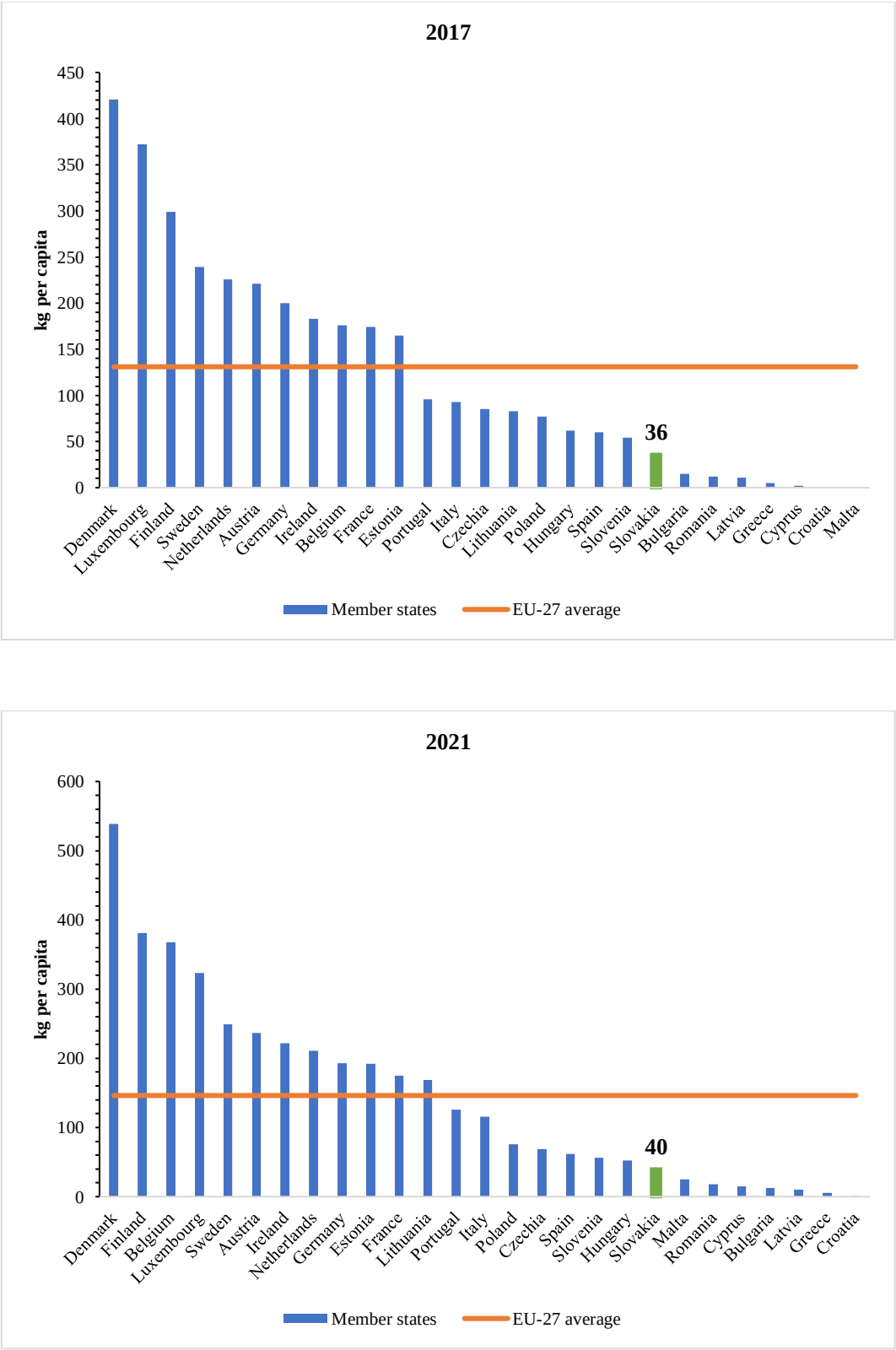


Figure 4. Disposal - incineration with energy recovery in EU-27 in 2017 and 2021 (kg per capita)

According to research, the residents of Germany, Finland, Sweden, the Netherlands, Belgium, and Denmark have the most efficient waste management systems, with almost no municipal waste directed to landfills in these countries. Most municipal waste is in landfills in Malta, with 51.9% in 2021. Behind Malta are Greece and Cyprus, with the highest landfilling rate across EU-27. Regarding SR, the landfilling rate is declining (2017: 22.9%; 2021: 20.2%) (Table 6).

Table 6. Disposal-landfill in EU-27 between 2017-2021 (kg per capita)

Criterium/Year	**2017**	**2018**	**2019**	**2020**	**2021**	**2021/2017**
EU-27	127	125	124	119	121	**95%**
Belgium	4	4	4	4	3	**75%**
Bulgaria	269	249	273	116	232	**86%**
Czechia	222	229	231	259	263	**118%**
Denmark	8	9	8	7	1	**13%**
Germany	5	5	5	5	2	**40%**
Estonia	75	87	64	56	78	**104%**
Ireland	130	86	96	104	100	**77%**
Greece	403	403	407	428	431	**107%**
Spain	242	255	241	229	245	**101%**
France	160	145	144	138	139	**87%**
Croatia	301	286	264	253	260	**86%**
Italy	114	107	105	98	78	**68%**
Cyprus	492	452	430	408	394	**80%**
Latvia	267	240	252	253	282	**106%**
Lithuania	149	114	102	79	74	**50%**
Luxembourg	36	35	35	31	32	**89%**
Hungary	186	189	196	218	212	**114%**
Malta	530	561	636	531	519	**98%**
Netherlands	7	7	7	7	7	**100%**
Austria	12	13	12	15	0	**0%**
Poland	132	137	145	138	140	**106%**
Portugal	227	245	244	292	224	**99%**
Romania	207	210	213	214	228	**110%**
Slovenia	48	47	52	33	31	**65%**
Slovakia	229	229	219	218	202	**88%**
Finland	5	4	5	3	3	**60%**
Sweden	2	3	3	2	2	**100%**

In 2017, the average European citizen disposed of 127 kg of municipal waste in landfills, while in SR, it was 292 kg per capita. In 2021, the average European citizen produced 121 kg of landfilled waste per capita, while in the SR, it was 202 kg per capita. The situation got better in both cases (Figure 5). To fully reap the benefits of the Circular Economy Action Plan, one of the primary components of the European Green Deal, the complete application of the EU's landfill regulations is a fundamental prerequisite. SR, on the other hand, still needs to implement these regulations fully. The European Commission has made public its decision to bring SR's case before the Court of Justice of the European Union for failing to reclaim and close several landfills, as announced by the European Commission; this goes against the requirements outlined in the EU Directive on Landfills from 1999.

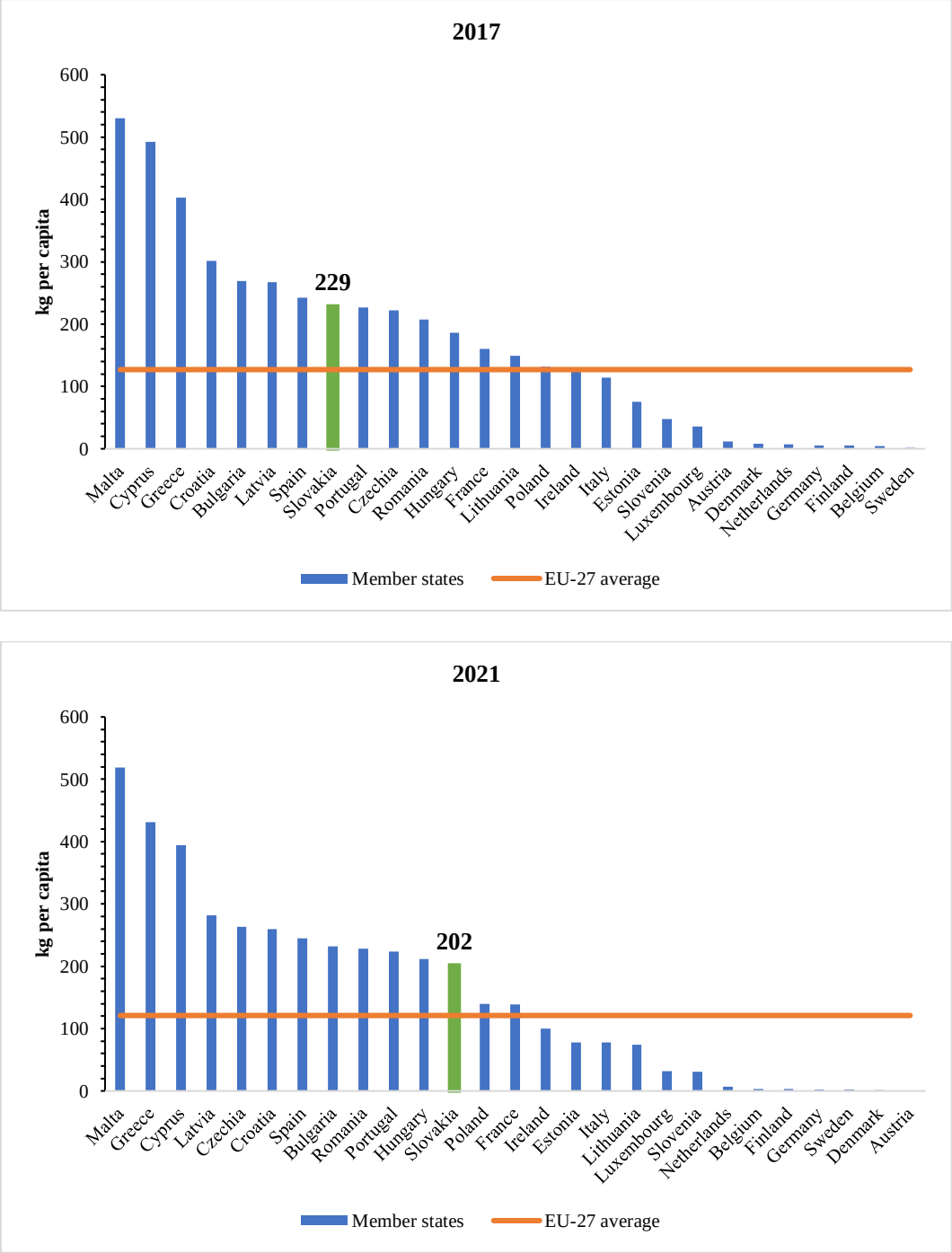


Figure 5. Disposal- landfill in EU-27 in 2017 and 2021 (kg per capita)

In the second part of our investigation into the efficiency of municipal waste management (Figure 6), we utilised composite indicators E_i. Germany maintained its position as the leader in waste management efficiency in both years under consideration (2017 and 2021), despite a 1.37 percentage point drop in its efficiency. Malta comes in last in both years; however, the country improved its performance by 28.44% between 2017 and 2021. Regarding SR, it took 18th place in 2017 and improved its efficiency by 13.69% in 2021. In addition to these two member states, Bulgaria took the 19th spot in 2021 after achieving a positional gain of 6.79%. Czechia climbed by 4.50% to take 20th place in 2021. The 2.68% increase in the position that Estonia received moved it up to the 14th spot in 2021. Ireland came in at number 12 with a score of 3.82%. France moved up 1.54%, moving it to the 13th position in 2021. Although it improved its score by 10.06%, Croatia finished in 24th place in 2021. Italy's final placing saw an improvement of 3.81%, which placed the country in seventh position in 2021. Although it experienced growth of 18.50%, Latvia finished in 17th place. Despite a 3.49% increase in efficiency, Poland came in 11th place in 2021. To finish in sixth place in 2021, Slovenia achieved an efficiency improvement of 1.09%.

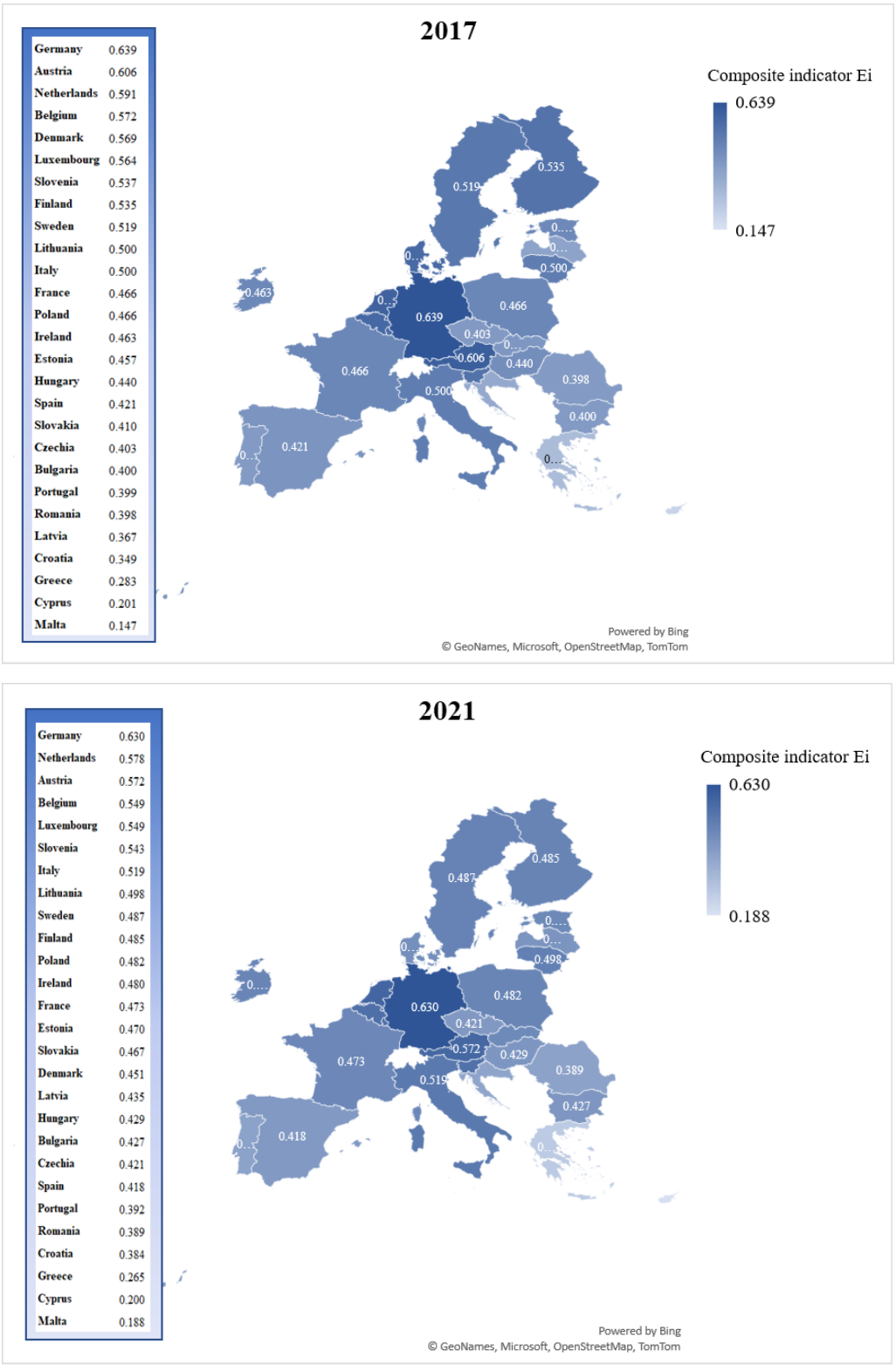


Figure 6. Comparison of composite indicators of EU-27 in 2017 and 2021

DISCUSSION

Overall results have shown disparities in municipal waste management across EU-27. Concerning the amount of municipal waste produced in the EU-27, it has grown in almost every member state. As demonstrated by Gardiner and Hajek (2020) in their research, where they indicate significant concern on a global scale is the correlation between rising economic activity and rising levels of waste production; we believe that there is a nexus between economic growth and produced municipal waste. Furthermore, a demonstrable link exists between household consumption and municipal waste production in European economies. It explains why countries such as Denmark and Luxembourg are among Europe's leading waste producers in 2017 and 2021. In 2035, the rate of recycling and landfilling will be critical factors in

determining whether the EU is successful in achieving its goals. The proposed reform package aims to transition the Union's economy to a circular model, requiring the recycling of not less than 65% of municipal waste by 2035 and limiting the amount of municipal waste destined for landfills to a maximum of 10%. The accomplishment of these objectives will be very challenging for SR as, within their waste strategies, they want to achieve at least 25% of landfilling by 2035.

It will be necessary, among other factors, to consider the composition of the materials used in producing the goods and their packaging as the actions and assist the state provides. Regarding people's behaviours, we can agree with Holotová *et al*. (2020) that people are becoming more environmentally aware. In general, the rate of recycling materials is increasing; however, there are a few obstacles; where in Europe, there is a need for high-performance composite recycling and recovery infrastructures because they are challenging to set up. Such materials lack recycling and recovery, particularly for emerging recyclable materials like plastics, where we agree with Hsu *et al*. (2021) that plastic waste went through non-circular treatment and exports. Consequently, an increased quantity of recyclables cannot be handled within European processing plants, thus necessitating the export of such materials for additional processing.

Moreover, waste materials and products present a further technical barrier. It is because certain materials are technically non-recyclable or are composed of mixed materials that are difficult to separate. However, as Mohammadi *et al*. (2019) acknowledged, non-recyclable waste is treated in waste-to-energy plants equipped with various technologies. Gui (2020) agrees with this statement by emphasising that the biggest challenge in developing countries is the need for a formal recycling infrastructure.In addition, certified compost requires improvement in most countries, including the SR. Siebert *et al*. (2020) explained that promoting sustainable recycling practices aims to produce high-quality compost and the material remaining after the anaerobic digestion of a biodegradable feedstock. On the other hand, it needs certified compost to cultivate organic food (Klopčič *et al.*, 2021).

Municipal authorities must comply with the criteria to obtain a quality certification regarding composting. Residents of family houses in SR were allowed to receive garden composters, and citizens of cities were allowed to apply for a free small brown plastic composter (Báreková *et al.*, 2020). Nowadays, most municipal waste is in landfills – 40.68% as of 2021. Currently, in SR, two facilities for the energy utilisation of waste are operating in Bratislava and Košice (Šyc *et al.,* 2018). For instance, in 2021, Austria no longer dumps any municipal waste, and Denmark only has one kg per capita. Denmark uses waste for incineration with energy recovery of 539 kg per capita and in SR only 40 kg per capita; however, the situation is improving compared to previous years.

Eventually, as previously mentioned, disparities in terms of waste management in EU-27 exist. We agree with Malinauskaite *et al.* (2017) that there needs to be more capacities for waste-to-energy recovery in the eastern part and potentially excessive ones in the northwest of member states. Importing and exporting waste would be one of the solutions to incinerate waste with energy recovery; however, public opinion could constrain it. There is also a risk of the high price of transportation. Overall, based on the waste management hierarchy, the prevention of waste, its minimisation, reuse, and recycling come before energy recovery. Therefore, we hypothesise that member states with high levels of landfilling (including SR) and low waste incineration capacities invest in recycling facilities first, analyse these facilities' long-term impacts, and then consider exporting waste to neighbouring countries.

It is crucial that the Waste Act No. 79/2015 Coll. undergo further amendments to prevent potential legal action from the European Commission in the future. An example of a legal case involves the European Union Court of Justice, which was presented with a lawsuit by the European Commission concerning the issue of landfills that have not been properly closed in SR. The plaintiff has initiated legal proceedings against SR on the grounds of non-compliance with Directive 2008/98/EC, alleging that the defendant has neglected to adequately address the repair and permanent closure of 21 decommissioned landfills. Likewise, municipalities in SR should amalgamate into more associations to collectively manage waste disposal.

CONCLUSION

This study examined the effects of regulatory strategies on the efficiency of municipal waste management in the SR compared to the EU-27 countries between 2017 and 2021. In a consumer society, the amount of municipal waste produced rises as the standard of living increases. Since the techniques used to facilitate waste production are most efficient at all levels, from the manufacturer to the consumer, reducing waste generation is of the utmost importance. Even though recycling encourages the development of a framework for resource utilisation that promotes the use of already disposed-off waste materials, there still needs to be an understanding among the general public about what waste is.

However, many things are reusable for various purposes. Recycling in the form of composting is more important to us regarding the amount of compostable biowaste generated than other forms of recycling (mainly within the municipal sphere). By properly setting up the composting process, we are able to achieve a 100% recycling compost rate, and every municipality should be required to do so. However, waste management still requires landfills because not all waste is recyclable (materially or energetically) so far; however, establishing new landfills is forbidden according to EU and Slovak legislation. Expressed by the composite indicator, Germany demonstrated the highest efficiency level (0.630), while Malta exhibited the lowest level of performance (0.188). During the assessed time frame spanning from 2017 to 2021, the efficiency of MWM experienced a notable increase of 28.4% in Malta, while conversely, it underwent a significant decrease of 20.8% in Denmark. Furthermore, we plan to continue our research aimed at removing illegal landfills and fulfilling the change of existing landfills to

energy recovery in selected EU member states according to the waste management hierarchy set by Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste.

ACKNOWLEDGMENT

This research was funded by the Slovak Research and Development Agency under Grant No. APVV-20-0076 entitled *"Waste and Construction - Modelling the Effectiveness of Alternative Options for Cooperation between Administrative Authorities."*

REFERENCES

Act No. 79/2015 Coll. on Waste. (in Slovak) Retrieved from: https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2015/79/20170101 (accessed on 28. January, 2023)

Banias, G., Batsioula, M., Achillas, C., Patsios, S.I., Kontogiannopoulos, K.N., Bochtis, D. and Moussiopoulos, N., 2020. A life cycle analysis approach for the evaluation of municipal solid waste management practices: The case study of the region of central Macedonia, Greece. *Sustainability*, *12*(19), p.8221.
DOI: 10.3390/su12198221

Báreková, A., Tátošová, L., Kišš, V. and Kováčová, M., 2020. Composition of the separated green waste in rural and urban areas. *Journal of ecological engineering*, *21*(5), pp.234-239.
DOI: 10.12911/22998993/123120

Cherubini, F., Bargigli, S. and Ulgiati, S., 2009. Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant, and incineration. *Energy*, *34*(12), pp.2116-2123.
DOI: 10.1016/j.energy.2008.08.023

Churchman, C.W. and Ackoff, R.L., 1954. An approximate measure of value. *Journal of the Operations Research Society of America*, *2*(2), pp.172-187.
DOI: 10.1287/opre.2.2.172

Corvellec, H., Stowell, A.F. and Johansson, N., 2022. Critiques of the circular economy. *Journal of Industrial Ecology*, *26*(2), pp.421-432.
DOI: 10.1111/jiec.13187

De Feo, G., Ferrara, C., Iannone, V. and Parente, P., 2019. Improving the efficacy of municipal solid waste collection with a communicative approach based on easily understandable indicators. *Science of the Total Environment*, *651*, pp.2380-2390.
DOI: 10.1016/j.scitotenv.2018.10.161

Dini, R., 2016. *Consumerism, waste, and reuse in twentieth-century fiction*. New York: Palgrave Macmillan. ISBN: 978-1-137-58165-5

Directive 1999/31 - Landfill of waste. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31999L0031 (accessed on 02. March 2023)

Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (Text with EEA relevance) Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.150.01.0109.01.ENG (accessed on 20. February 2023)

Dobbs, M., Gravey, V. and Petetin, L., 2021. Driving the European Green Deal in turbulent times. *Politics and Governance*, *9*(3), pp.316-326.
DOI: 10.17645/pag.v9i3.4321

EEA(1). Municipal waste landfill rates in Europe by country. Retrieved from https://www.eea.europa.eu/data-and-maps/figures/municipal-waste-landfill-rates-in-1 (accessed on 10. March 2023)

EEA(2). Municipal waste recycling rates in Europe by country. Retrieved from https://www.eea.europa.eu/data-and-maps/figures/municipal-waste-landfill-rates-in-1 (accessed on 11. March 2023)

European Parliament. 2016. Closing the loop – New circular economy package. Retrieved from https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573899/EPRS_BRI%282016%29573899_EN.pdf (accessed on 15. April 2023)

Eurostat. 2023. Municipal waste by waste management operations. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/env_wasmun/default/table?lang=en (accessed on 20. February 2023)

Fetting, C., 2020. The European Green Deal. *ESDN Report, December*. Retrieved from https://www.esdn.eu/fileadmin/ESDN_Reports/ESDN_Report_2_2020.pdf (accessed on 25. January 2023)

Gardiner, R. and Hajek, P., 2020. Municipal waste generation, R&D intensity, and economic growth nexus–A case of EU regions. *Waste Management*, *114*, pp.124-135.
DOI: 10.1016/j.wasman.2020.06.038

Gharfalkar, M., Campbell, C., Ali, Z. and Hillier, G., 2015. Analysis of Waste Hierarchy in the Waste Directive 2008/98/EC. *Waste Management*.
DOI: 10.1016/j.wasman.2015.02.007

Ginga, C.P., Ongpeng, J.M.C. and Daly, M.K.M., 2020. Circular economy on construction and demolition waste: A literature review on material recovery and production. *Materials*, *13*(13), p.2970.
DOI: 10.3390/ma13132970

Gui, L., 2020. Recycling infrastructure development under extended producer responsibility in developing economies. *Production and Operations Management*, *29*(8), pp.1858-1877.
DOI: 10.1111/poms.13202

Holotová, M., Nagyová, Ľ. and Holota, T., 2020. The impact of environmental responsibility on changing consumer behaviour–sustainable market in Slovakia. *Economics & Sociology*, *13*(3), pp.84-96.
DOI: 10.14254/2071-789X.2020/13-3/6

Hsu, W.T., Domenech, T. and McDowall, W., 2021. How circular are plastics in the EU?: MFA of plastics in the EU and pathways to circularity. *Cleaner Environmental Systems*, *2*, p.100004.
DOI: 10.1016/j.cesys.2020.100004

Khan, I., Hou, F. and Le, H.P., 2021. The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America. *Science of the Total Environment*, *754*, p.142222.
DOI:10.1016/j.scitotenv.2020.142222

Khomenko, I., Vuychenko, M., Gomeniuk, M., Mazur, Y. and Haidai, O., 2021. Imperatives for the formation and development of the circular economy and global waste management. In *E3S Web of Conferences* (Vol. 255, p. 01034). EDP Sciences.
DOI: 10.1051/e3sconf/202125501034

Kirchherr, J., Reike, D. and Hekkert, M., 2017. Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, conservation and recycling*, *127*, pp.221-232.
DOI: 10.1016/j.resconrec.2017.09.005

Klopčič, M., Erjavec, K., Waldrop, M., Roosen, J., Engel, P., Galama, P. and Kuipers, A., 2021. Consumers' and farmers' perceptions in Europe regarding the use of composted bedding material from cattle. *Sustainability*, *13*(9), p.5128.
DOI: 10.3390/su13095128

Knorr, D. and Augustin, M.A., 2022. From Food to Gods to Food to Waste. *Critical Reviews in Food Science and Nutrition*, pp.1-19.
DOI: 10.1080/10408398.2022.2153795

Lazikova, J. and Rumanovská, Ľ., 2022. Nutrition and health claims on foods in the EU legislation. *Juridical Tribune/Tribuna Juridica*, *12*(2).
DOI: 10.24818/TBJ/2022/12/2.08

Liang, G., Panahi, F., Ahmed, A.N., Ehteram, M., Band, S.S. and Elshafie, A., 2021. Predicting municipal solid waste using a coupled artificial neural network with archimedes optimisation algorithm and socioeconomic components. *Journal of Cleaner Production*, *315*, p.128039.
DOI: 10.1016/j.jclepro.2021.128039

MacArthur, E., 2013. Towards the circular economy. *Journal of Industrial Ecology*, *2*(1), pp.23-44. Retrieved from https://www.werktrends.nl/app/uploads/2015/06/Rapport_McKinsey-Towards_A_Circular_Economy.pdf (accessed on 15. February 2023)

Malinauskaite, J., Jouhara, H., Czajczyńska, D., Stanchev, P., Katsou, E., Rostkowski, P., Thorne, R.J., Colon, J., Ponsá, S., Al-Mansour, F. and Anguilano, L., 2017. Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. *Energy*, *141*, pp.2013-2044.
DOI: 10.1016/j.energy.2017.11.128

Maradana, R.P., Pradhan, R.P., Dash, S., Zaki, D.B., Gaurav, K., Jayakumar, M. and Sarangi, A.K., 2019. Innovation and economic growth in European Economic Area countries: The Granger causality approach. *IIMB Management Review*, *31*(3), pp.268-282.
DOI: 10.1016/j.iimb.2019.03.002.

Marišová,E., Fandel,P., 2022. Basic visions of Slovakia's environmental strategies: a case study in two selected regions. In Strategy and innovations in the raw materials policy of the Slovak Republic and the EU - historical development of the importance of raw materials. *Košice: Technická univerzita*, pp.99-115. ISBN 978-80-553-4187-3.

Marín, I., Demaria, F., Ofelio, C., Serra, L.M., Turiel, A., Ripple, W.J., Mukul, S.A. and Costa, M.C., 2022. Scientists' warning against the society of waste.
DOI: 10.1016/j.scitotenv.2021.151359

Ministry of Environment of the Slovak Republic(1). 2018. Waste prevention program of the Slovak Republic for the years 2019-2025. (in Slovak) Retrieved from https://www.minzp.sk/files/sekcia-enviromentalneho-hodnotenia-riadenia/odpady-a-obaly/registre-a-zoznamy/ppvo-sr-19-25.pdf (accessed on 22. February, 2023)

Ministry of Environment of the Slovak Republic(2). 2020. Greener Slovakia – Strategy of the Environment of the Slovak Republic until 2030. Retrieved from https://www.minzp.sk/files/iep/publikacia_zelensie-slovensko-aj_web.pdf (accessed on 20. February 2023)

Ministry of Environment of the Slovak Republic(3). 2021. Waste management program of the Slovak Republic for the years 2021–2025. (in Slovak) Retrieved from https://www.minzp.sk/files/sekcia-enviromentalneho-hodnotenia-riadenia/odpady-a-obaly/registre-a-zoznamy/poh_sr_2021_2025_vestnik.pdf (accessed on 20. February, 2023)

Mohammadi, M., Jämsä-Jounela, S.L. and Harjunkoski, I., 2019. Optimal planning of municipal solid waste management systems in an integrated supply chain network. *Computers & Chemical Engineering*, *123*, pp.155-169.
DOI: 10.1016/j.compchemeng.2018.12.022

Our World in Data. (2023). World Population Growth. Retrieved from https://ourworldindata.org/world-population-growth (accessed on 12. February 2023)

Pires, A. and Martinho, G., 2019. Waste hierarchy index for circular economy in waste management. *Waste Management*, *95*, pp.298-305.
DOI: 10.1016/j.wasman.2019.06.014

Ripple, W.J., Wolf, C., Newsome, T.M., Galetti, M., Alamgir, M., Crist, E., Mahmoud, M.I., Laurance, W.F. and 15,364 Scientist Signatories from 184 Countries, 2017. World scientists' warning to humanity: a second notice. *BioScience*, *67*(12), pp.1026-1028.
DOI: 10.1093/biosci/bix125

Rusch, M., Schöggl, J.P. and Baumgartner, R.J., 2022. Application of digital technologies for sustainable product management in a circular economy: A review. *Business Strategy and the Environment*.
DOI: 10.1002/bse.3099

Smol, M., Duda, J., Czaplicka-Kotas, A. and Szołdrowska, D., 2020. Transformation towards a circular economy (CE) in municipal waste management system: Model solutions for Poland. *Sustainability*, *12*(11), p.4561.
DOI: 10.3390/su12114561

Siebert, S., Gilbert, J. and Ricci-Jürgensen, M., 2020. Compost production in Europe. *ECN Report*. Retrieved from https://www.compostnetwork.info/wordpress/wp-content/uploads/190823_ECN-Compost-Production-in-Europe_final_layout-ECN.pdf (accessed on 10. March 2023)

Sommer, V. and Walther, G., 2021. Recycling and recovery infrastructures for glass and carbon fiber reinforced plastic waste from wind energy industry: A European case study. *Waste Management*, *121*, pp.265-275.
DOI: 10.1016/j.wasman.2020.12.021

Spišáková, M., Mandičák, T., Mésároš, P. and Špak, M., 2022. Waste Management in a Sustainable Circular Economy as a Part of Design of Construction. *Applied Sciences*, *12*(9), p.4553.
DOI: 10.3390/app12094553

Stanescu, M.D., 2021. State of the art of post-consumer textile waste upcycling to reach the zero waste milestone. *Environmental Science and Pollution Research*, *28*(12), pp.14253-14270.
DOI: 10.1007/s11356-021-12416-9

Statistical Office of the SR. Relative indicators from the area of treatment with municipal waste [zp3002rr]. Retrieved from https://datacube.statistics.sk/#!/view/en/VBD_SK_WIN/zp3002rr/v_zp3002rr_00_00_00_en (accessed on 25. February 2023)

Stillwell, W.G., Seaver, D.A. and Edwards, W., 1981. A comparison of weight approximation techniques in multiattribute utility decision making. *Organizational behavior and human performance*, *28*(1), pp.62-77.
DOI: 10.1016/0030-5073(81)90015-5

Šyc, M., Krausová, A., Kameníková, P., Šomplák, R., Pavlas, M., Zach, B., Pohořelý, M., Svoboda, K. and Punčochář, M., 2018. Material analysis of Bottom ash from waste-to-energy plants. *Waste Management*, *73*, pp.360-366.
DOI: 10.1016/j.wasman.2017.10.045

Taelman, S.E., Tonini, D., Wandl, A. and Dewulf, J., 2018. A holistic sustainability framework for waste management in European cities: Concept development. *Sustainability*, *10*(7), p.2184.
DOI: 10.3390/su10072184

United Nations. (2022). Day of Eight Billion. Retrieved from https://www.un.org/en/dayof8billion (accessed on 19. February 2023)

Van Ewijk, S. and Stegemann, J.A., 2016. Limitations of the waste hierarchy for achieving absolute reductions in material throughput. *Journal of Cleaner Production*, *132*, pp.122-128.
DOI: 10.1016/j.jclepro.2014.11.051

Van Kerckhove, G., 2012. *Toxic capitalism: The orgy of consumerism and waste: Are we the last generation on earth?*. AuthorHouse. ISBN 978-1-4772-1905-8

Velenturf, A.P.M. and Purnell, P., 2021. Principles for a sustainable circular economy. Sustainable Production and Consumption, v. 27.
DOI: 10.1016/j.spc.2021.02.018

Weigend Rodríguez, R., Pomponi, F., Webster, K. and D'Amico, B., 2020. The future of the circular economy and the circular economy of the future. *Built Environment Project and Asset Management*, *10*(4), pp.529-546.
DOI: 10.1108/BEPAM-07-2019-0063

Wolf, S., Teitge, J., Mielke, J., Schütze, F. and Jaeger, C., 2021. The European Green Deal—more than climate neutrality. *Intereconomics*, *56*, pp.99-107.
DOI: 10.1007/s10272-021-0963-z

Yu, Z., Khan, S.A.R., Ponce, P., Muhammad Zia-ul-haq, H. and Ponce, K., 2022. Exploring essential factors to improve waste-to-resource recovery: A roadmap towards sustainability. *Journal of Cleaner Production*, *350*, p.131305.
DOI: 10.1016/j.jclepro.2022.131305

Zbicinski, I., 2006. *Product design and life cycle assessment* (Vol. 3). Baltic University Press. ISBN 91-975526-2-3.

Zhang, C., Hu, M., Di Maio, F., Sprecher, B., Yang, X. and Tukker, A., 2022. An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe. *Science of the Total Environment*, *803*, p.149892.
DOI: 10.1016/j.scitotenv.2021.149892