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Article

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Amfiteatru Economic

Provided in Cooperation with:

The Bucharest University of Economic Studies

Suggested Citation: Pîrvu, Ramona; Ionescu, George H.; Jianu, Elena; Nastase, Luiza Loredana; Bratu, Raducu Ștefan (2023) : E-Waste and Responsible Consumption in EU Countries – Developments and Forecasts 2025-2030, Amfiteatru Economic, ISSN 2247-9104, The Bucharest University of Economic Studies, Bucharest, Vol. 25, Iss. 62, pp. 147-162, <https://doi.org/10.24818/EA/2023/62/147>

This Version is available at:

<https://hdl.handle.net/10419/281696>

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E-WASTE AND RESPONSIBLE CONSUMPTION IN EU COUNTRIES – DEVELOPMENTS AND FORECASTS 2025-2030

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Please cite this article as:

Pîrvu, R., Ionescu, G.H., Jianu, E., Năstase, L.L. and Bratu, R.Ș., 2023. E-Waste and Responsible Consumption in EU Countries – Developments and Forecasts 2025-2030. *Amfiteatru Economic*, 25(62), pp. 147-162.

DOI: [10.24818/EA/2023/62/147](https://doi.org/10.24818/EA/2023/62/147)

Article History

Received: 29 September 2022

Revised: 29 November 2022

Accepted: 20 December 2022

Abstract

Monitoring of Member States' compliance with quantitative targets for the collection of electrical and electronic waste, preparation for reuse, recycling, and recovery of such waste is carried out based on Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment.

Through the research carried out, our aim is to highlight the degree of achievement of the targets set at the level of the European Union countries regarding the management of waste electrical and electronic equipment, as well as the dynamics of adaptation to the increasingly stringent European requirements in the context of the transition to a low-carbon and circular economy, thus filling an information gap on this topic of major importance. Based on the data published so far by EU member states, using the autoregressive integrated moving average (ARIMA) forecasting model, we have extrapolated the 2010-2018 trends in the indicators for the management of waste electrical and electronic equipment, thus providing a useful insight into their potential evolution until 2030.

At the same time, the analysis of the results obtained allows us to observe the degree of achievement of the targets set, as well as the dynamics of adaptation to the increasingly stringent European requirements on the management of waste electrical and electronic equipment in the context of the transition to a low-carbon economy based on circular principles.

Keywords: electronic waste (e-waste); electrical and electronic equipment (EEE); recycling rate; circular economy; sustainable development; 2030 Agenda; e-waste management; environmental sustainability; ARIMA model.

JEL classification: Q53, Q56

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Introduction

The management of waste in an environmentally friendly way is an important part of the European Union's environmental policy. By improving waste management, encouraging recycling, and limiting/reducing the amount of waste going to landfill, the European Union's waste policy contributes to the move towards a circular economy.

Recent research supports the importance of moving from linear to circular economic model within the European Union, with new technologies that extend the life of products, allow for the remanufacturing of components and materials, and to specialized collection and recycling (López-Portillo et al., 2021; Manea et al., 2021). The idea of economic growth through the transition to a modern and efficient economy that promotes optimal use of resources is also presented in the European Green Pact, which also aims to achieve the sustainable development goals of the 2030 Agenda of the United Nations (European Commission, 2019). The management of electronic waste is closely linked to 6 of the 17 Sustainable Development Goals of the 2030 Agenda, targeting health and well-being, clean water and sanitation, sustainable cities and communities, responsible consumption and production, life under water, but also decent work and economic growth, according to Baldé et al. (2017).

The European Parliament (European Parliament, 2012) defines waste electrical and electronic equipment (WEEE) as electrical and electronic equipment that constitutes waste according to Article 3(1) of Directive 2008/98/EC, including components and consumables of the product that now becomes waste. According to the Step Initiative (2014), e-waste (waste electrical and electronic equipment) covers all types of electrical and electronic equipment (EEE) and their parts that have been discarded by the owner as waste without the intention of reuse. Thus, this definition includes almost any household or business item that contains electrical circuits or components, powered or battery-operated.

Data published by the Global Transboundary E-waste Flows Monitor 2022 (Baldé et al., 2022) show that e-waste has seen an extremely rapid increase in flows compared to other types of waste. The global population generated 53.6 Mt of electronic waste in 2019, which is predicted to increase to 74.7 Mt by 2030 if both policy makers and all stakeholders do not mobilize. The same document states that Europe has generated 12Mt of e-waste and has the largest export centers for e-waste, as well as being able to process e-waste.

In the European Union, the latest statistics show that around 40% of electronic waste is recycled. This includes large household appliances, consumer electrical equipment and photovoltaic panels, IT and telecommunications equipment, small household appliances, medical devices, power tools, etc. EEE waste contains materials that are harmful both to the environment and to those who encounter them in the collection and recycling process (assembly/disassembly). To avoid all these dangerous situations, the rules adopted by the European Union on WEEE are indispensable.

To analyze the degree of achievement of the targets set at the level of countries of the European Union for the management of waste electrical and electronic equipment by 2030, we set out to analyze the dynamics of the evolution of the main indicators reflecting the adaptation of EU member states to the increasingly stringent European requirements in the context of the transition towards a low carbon and circular economy. To carry out this research, we selected five relevant indicators based on data provided by Eurostat and used the econometric tool

considered in the literature as the most appropriate for the purpose of the research, namely the autoregressive integrated moving average (ARIMA) forecasting model.

This investigative approach aims to provide a pool of relevant information, as well as a basis for reflection to all stakeholders, on the potential medium- and long-term developments in the collection, treatment, and recycling of waste electrical and electronic equipment and the achievement of the EU targets. In view of the challenge of the transition to a circular economy, the results of our research reduce the existing information gap on this topic, and thus contribute to supporting national and European efforts.

The introduction of the paper is followed by three sections. The first section corresponds to the review of the scientific literature, in which we have deepened the documents and materials relevant to the researched topic, followed by a section in which we have presented the five indicators used in the research, as well as Eurostat methodologies and the ARIMA model. The third section refers to the results and discussions on the topic researched. The conclusions complete the analysis with a summary of the main contributions of this paper, highlighting the novelties included.

1. Review of the scientific literature

The issue of recycling also covers waste electrical and electronic equipment, which is regulated by the European Union, both through general and specific rules and laws, with the aim of ensuring that the production and consumption of electrical and electronic equipment correspond to a sustainable circular economy. Proper management of electrical and electronic waste requires, on the one hand, greater attention to hazardous component materials, which affect the environment, soil, water, plant, animal, and human health, and, on the other hand, greater recovery and recovery of secondary, rare component materials (gold, platinum, cobalt) in future production (Cesaro et al., 2018).

Studies on e-waste are varied, highlighting the approaches of governments and all stakeholders to the issue, but also pointing to a number of shortcomings in the implementation of specific regulations. In their study on the implementation of the circular economy in the electrical and electronic equipment sector, based on qualitative data collected from 31 companies developed through the EU-funded CIRC4Life project, Rizos and Bryhn (2022) identified as barriers to circular economy business models in EEE the lack of transparency in supply chains, weak enforcement of EU regulations on waste and especially WEEE, limited circularity requirements in public procurement, lack of circular economy standards, but also lack of incentives for the collection of unused devices.

An important part of the circular economy is also considered waste treatment, through recycling and composting of used materials, but also through energy recovery from waste. The issue of waste treatment in the European Union has been addressed by López-Portillo et al. (2021), who concluded that although in terms of the regulations adopted there is a similarity in recycling rates across EU Member States, there are also differences in approach, which are attributed to variables such as R&D expenditure, resource productivity, years of membership of the European Union, and economic performance measured by real GDP per capita. The hypothesis that municipal solid waste management performance is closely related to a country's economic development is also found in Ríos and Picazo-Tadeo (2021). Based

on a linear regression model, Banacu et al. (2019) showed that R&D spending, private investment, and resource productivity positively and directly influence the recycling rate of municipal waste in EU member states, while an increase in environmental taxes may lead to a decrease in the recycling rate as investors will no longer be tempted to engage in green projects.

Kumar et al. (2022) have also addressed sustainable management of WEEE by extending the analysis to emerging economies. According to the study based on the analysis of 23 potential factors conducive to sustainable management of WEEE, the most important factors are R&D capabilities, digitization, extended producer responsibility, monitoring of dumping and illegal imports of waste, but also environmental regulations (including WEEE, use of green technologies in the recycling process).

Affordable prices and the rapid technological advancement of technical and technological equipment contribute to increased consumer demand and, at the same time, increasing e-waste. Eco-friendly purchases should be taken into account by consumers to avoid negative impact not only on the environment but also on human health. At the same time, refurbishment, repair, and reuse of appliances are necessary and mandatory in order to avoid the formation of WEEE. Sonogo et al. (2022) propose the extension of life cycles of electronic products to help decrease the use of finite resources, the emission of pollutants, and the increase of landfill waste.

In the same context, Constantinescu et al. (2022) consider that there is definitely a link between eco-investment and the level of e-waste recycling in EU countries. Thus, they observed an increasing trend of eco-investments in the period 2008-2018 in most EU countries, which may contribute positively to the collection and recycling of EEE in the context of a circular economy.

In the European Union, WEEE data are collected from Member States under Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on electrical and electronic waste (European Parliament, 2012). The purpose of collecting these data is to monitor Member States' compliance with the quantitative targets for the collection of electrical and electronic waste, its preparation for re-use and recycling and its recovery, as laid down in Article 7 (collection rate) and Article 11 and Annex V (recovery targets) of the above-mentioned Directive.

To achieve the research objective, we aimed to use the data published so far by the EU member states for the period 2010-2018 to obtain with the help of econometric tools an insight into the dynamics and potential of European countries to achieve high performance in terms of collection, treatment, and recycling of waste electrical and electronic equipment, in order to reach the EU targets.

2. Research methodology

Based on data published by Eurostat (Eurostat, 2022), five indicators relevant to the research were selected as follows: the amount of electrical and electronic equipment placed on the market, the amount of electrical and electronic waste collected, the amount of electrical and electronic waste treated in authorized facilities, the amount of electrical and electronic waste reused and recycled, together with the recycling rate of electrical and electronic waste (Table no. 1).

Table no. 1. Indicators used in research

Indicator	Name	U.M.
EEE_MKT	Electrical and electronic equipment introduced on the market	Kg/inhabitant
WEEE_COL	Waste electrical and electronic equipment	Kg/inhabitant
WEEE_TRT	Electrical and electronic waste is treated in authorized installations	Kg/inhabitant
WEEE_REC	Electronic and electrical waste is reused and recycled	Kg/inhabitant
WEEE_RATE	Recycled rate of the waste electric and electronic equipment	Percentage

Source: Eurostat data processing

According to the Eurostat methodology, the recycling rate of electrical and electronic waste is calculated by multiplying the collection rate by the recycling and reuse rate set out in Directive 2012/19/EU. The collection rate is equal to the volumes of electrical and electronic waste collected in the reference year divided by the average quantity of electrical and electronic waste placed on the market in the last three years (both expressed in units of mass).

Following the objective of the proposed research, respectively, to obtain relevant information on the potential evolution of the dynamics and the potential of EU countries to achieve high performance in terms of collection, treatment, and recycling of WEEE in the circular economy paradigm, we used the autoregressive integrated moving average (ARIMA) forecasting model as the econometric tool considered by the literature to be the most appropriate for the purpose of the research.

The ARIMA methodology proposed by Box and Jenkins (1976; Box, Jenkins and Reinsel, 1994), which is a generalization of the autoregressive moving average model (ARMA), was used to forecast the specific data series of the 120 specific indicators included in the analysis. This methodology was chosen due to its predictive power and flexibility in forecasting future trends (Abraham and Ledolter, 1983; Brockwell and Davis, 2002; Kufel, 2020; Hernandez-Matamoros et al., 2020).

In modelling the univariate time series, a frequently used approach is represented by self-regressive models (AR models). These include applying the linear regression function to the current value of the time series as compared to one or several values of the same time series, based on equation (1):

$$S_t = \alpha + \beta_1 S_{t-1} + \beta_2 S_{t-2} + \dots + \beta_p S_{t-p} + \varepsilon_t \quad (1)$$

where:

S_t = time series

$\alpha = (1 - \sum_{i=1}^p \beta_i) \gamma$, with γ the average of the process

β_1, \dots, β_p = the parameters of the process

p = the order of the AR model

ε_t = white noise.

In this context, mobile average prognosis models (MA models) are used in the analysis and modelling of univariate time series. These models rely on the linear regression of the most recent time-series value as compared to the white noise of some or several previous values

for the same time series. In this approach, it is presumed that the random shocks for a certain moment rely on the same data distribution, usually considered a normal distribution, according to equation (2):

$$S_t = \mu + W_t - \beta_1 W_{t-1} - \beta_2 W_{t-2} - \dots - \beta_q W_{t-q} \quad (2)$$

where:

S_t = time series

μ = series average

β_1, \dots, β_q = parameters of the model

q = order of the MA model

W_{t-i} = white noise

3. Results and discussion

Under Directive 2012/19/EU, EU member states must achieve a minimum annual collection rate of 65% of the quantity of electrical and electronic equipment placed on the market or, alternatively, a collection rate of 85% of the waste electrical and electronic equipment generated on their territory. It also provides that Member States may set even more ambitious collection rates for separate collection of waste electrical and electronic equipment and report this to the European Commission.

According to the methodology described in the previous section, for each selected variable and for each EU Member State, the relevant values for the years 2025 and 2030 have been forecasted. By analyzing the data obtained, we will be able to observe the degree of achievement of the assumed targets, as well as the dynamics of adaptation to the increasingly stringent European requirements on the management of waste electrical and electronic equipment in the context of the transition towards a low-carbon and circular economy.

The first variable selected for analysis concerns the quantity of EEE put on the market (Table no. 2).

Table no. 2. Evolution of the quantity of electrical and electronic equipment introduced in the marked in the period 2010-2030 (kg / person)

Country	2010	2018	2025	2030
Belgium	27.03	27.23	23.31	22.15
Bulgaria	6.92	11.65	17.98	22.51
The Czech Republic	15.85	18.52	19.93	21.10
Denmark	26.60	30.35	37.13	41.95
Germany	21.16	28.65	41.04	50.23
Estonia	9.91	14.46	17.11	19.59
Ireland	21.13	20.83	20.32	20.33
Greece	16.03	13.59	20.28	25.07
Spain	16.03	15.44	23.28	28.88
France	25.23	28.81	34.60	38.73

Country	2010	2018	2025	2030
Croatia	N/A	14.99	27.23	35.98
Italy	18.85	24.50	50.13	68.96
Cyprus	23.12	13.80	6.11	0.61
Latvia	7.29	12.59	16.70	19.64
Lithuania	7.75	12.70	16.55	19.42
Luxembourg	33.57	20.99	16.59	13.44
Hungary	12.42	23.53	20.14	20.57
Malta	34.48	21.40	13.84	6.62
Netherlands	N/A	28.56	36.90	44.53
Austria	19.83	26.41	38.25	46.78
Poland	12.8	17.39	21.78	24.91
Portugal	14.86	17.60	33.28	44.49
Romania	7.47	13.41	23.96	31.47
Slovenia	13.88	17.44	19.95	22.04
Slovakia	9.14	13.56	19.93	24.50
Finland	27.62	24.08	17.65	14.62
Sweden	24.78	28.31	31.23	33.67
EU-27	17.95	23.02	39.36	51.05

Analyzing the results obtained, we note that for the period 2019-2030, the average quantity of electrical and electronic equipment placed on the European Union market is expected to grow steadily, with an increase of 70.98% in 2025 compared to 2018, and in 2030 the increase could be more than double, reaching an increase of 117.64%. However, in terms of dynamics, the growth phenomenon is not similar for all Member States. There are countries for which growth rates are estimated to be significantly higher than the EU average, mainly countries with lower than average European consumption of electrical and electronic equipment due to their existing economic and social characteristics.

It is also worth mentioning countries for which a reduction in consumption of electrical and electronic equipment is expected by 2030 compared to 2018, such as Belgium (-18.95%), Luxembourg (-35.97%), or Finland (-39.29%). A possible explanation for this phenomenon may be the increasing awareness of consumers about the negative environmental effects of the consumption of electrical and electronic equipment, as well as the increase in the average duration of use/lifetime of existing equipment, which could lead to reduced demand for the purchase of new equipment.

The results of the application of the research methodology to the data on the amount of electrical and electronic waste collected are presented in Table no. 3.

**Table no. 3. Evolution of the quantity of electrical and electronic waste collected
in the period 2010-2030 (kg / resident)**

Country	2010	2018	2025	2030
Belgium	9.69	12.10	13.12	14.19
Bulgaria	6.09	7.49	9.82	11.49
The Czech Republic	5.06	8.76	13.34	16.20
Denmark	14.95	12.29	9.96	8.30
Germany	9.50	10.29	11.75	12.79
Estonia	4.23	7.57	10.66	12.86
Ireland	9.74	12.88	19.66	24.64

Country	2010	2018	2025	2030
Greece	4.18	5.41	6.95	8.05
Spain	3.39	6.85	9.36	11.46
France	6.69	12.16	16.87	20.24
Croatia	N/A	10.15	16.21	20.54
Italy	9.83	6.97	2.64	0.60
Cyprus	3.15	3.81	5.18	5.99
Latvia	2.04	5.22	10.70	14.63
Lithuania	2.88	5.08	7.90	9.30
Luxembourg	9.51	9.98	10.97	11.44
Hungary	4.05	7.15	11.97	15.41
Malta	3.70	6.55	9.40	11.43
Netherlands	7.71	10.70	13.92	16.22
Austria	8.88	13.17	20.38	25.46
Poland	2.95	6.73	9.92	12.16
Portugal	4.41	7.17	9.47	11.17
Romania	1.30	3.28	7.53	10.57
Slovenia	4.23	6.48	8.43	9.90
Slovakia	4.07	5.85	8.55	10.48
Finland	9.48	12.09	14.12	15.58
Sweden	17.21	14.19	11.76	9.73
EU-27	6.91	8.94	12.42	14.91

There is a growing concern at EU level about the collection of electrical and electronic waste, which is reflected in the results of the analysis of available data. The forecast of the evolution of the average amount of electrical and electronic waste collected at the EU level shows that it will increase by 38.93% by 2025 compared to 2018, with an upward trend until 2030, when it will potentially increase by 66.78% compared to 2018.

Analyzing the results obtained, we can state that a significant number of Member States can be identified that recorded values of this indicator above the European average in 2018 and are expected to have the same above-average values by 2030, including the Czech Republic, Ireland, France, Croatia, the Netherlands, Austria and Finland. An increase in performance in WEEE collection during the period under review can be seen in two EU member states. In the case of Latvia, an increase in the amount collected from 5.22 kg/inhabitant in 2018 (below the EU average of 8.94 kg/inhabitant) to 14.63 kg/inhabitant in 2030 (above the EU average of 14.91 kg/inhabitant) is noted, and in the case of Hungary it is estimated that the amount collected by 2030 will double from 7.15 kg/inhabitant in 2018 (below the EU average) to 15.41 kg/inhabitant (above the EU average).

Similar results are presented by Boubellouta and Kusch-Brandt (2021), who demonstrated a unidirectional causal relationship between economic growth and uncollected and unrecycled / unused electronic waste. Similarly, de van Fan et al. (2021) identified a strong linear correlation between WEEE and GDP, but this correlation does not hold for the GDP per capita variable. Therefore, a country with the highest GDP per capita (Luxembourg) is not also the country with the highest number of WEEE (Sweden), similar to the results obtained by the present research.

Table no. 4 summarizes the results on the possible development of the amount of WEEE treated in licensed facilities in the period 2019-2030. In terms of the average amount of waste

treated at the EU level, an upward trend can be observed, so that in 2025 an average amount of 11.52 kg/person is expected to be treated in licensed facilities (representing an increase of 31.07% compared to 2018), and in 2030 the average amount of waste treated is expected to increase to 13.54 kg/person (representing an increase of 54.04% compared to 2018).

Table no. 4. Evolution of the quantity of electrical and electronic equipment waste treated in authorized facilities in the period 2010-2030 (kg / person).

Country	2010	2018	2025	2030
Belgium	9.53	11.05	12.48	13.50
Bulgaria	6.08	6.68	9.13	10.55
The Czech Republic	5.18	8.29	11.06	13.74
Denmark	14.73	6.47	4.77	1.33
Germany	9.39	10.29	11.66	12.63
Estonia	4.23	7.57	10.65	12.85
Ireland	9.56	12.89	19.67	24.66
Greece	4.63	5.44	6.63	7.48
Spain	3.01	6.97	9.42	11.61
France	6.36	12.16	17.13	20.68
Croatia	3.99	9.26	13.87	17.17
Italy	14.13	7.15	1.49	0.0 ^a
Cyprus	2.82	3.81	4.70	5.40
Latvia	1.91	4.86	9.13	12.19
Lithuania	2.96	5.04	6.71	7.97
Luxembourg	9.51	9.98	10.69	11.16
Hungary	3.98	7.00	10.78	13.48
Malta	2.21	6.53	8.55	10.41
Netherlands	7.71	9.64	11.45	12.96
Austria	8.88	13.17	20.38	25.46
Poland	2.76	6.74	9.79	12.07
Portugal	4.41	7.17	9.48	11.20
Romania	1.30	3.04	6.78	9.45
Slovenia	4.07	6.56	8.07	9.50
Slovakia	4.11	5.80	7.31	8.39
Finland	9.45	12.09	14.12	15.61
Sweden	17.13	14.19	11.82	9.85
EU-27	7.35	8.79	11.52	13.54

^a minimum forecasted.

Among the EU Member States for which results above the European average compared to 2018 are expected are Ireland (+91.31%), Latvia (+150.82%), Hungary (+92.57%) and Austria (+93.32%). A special case is represented by Romania, for which an increase is expected, in relative terms, significantly higher than the European average, and it is expected that by 2030 the amount of waste electrical and electronic equipment treated in licensed facilities will increase by 222.86%. The same analysis shows that, in absolute terms, the amount of waste treated in authorized facilities in Romania will still be below the European average in 2030, but the extremely low amount of waste treated in 2018 compared to the EU average has influenced the achievement of a growth rate more than double the similar rate at the EU level. In the same context, a number of Member States that have consistently

performed above the EU average can be mentioned, such as the Czech Republic, Ireland, France, Croatia, Austria, and Finland.

Table no. 5. The evolution of the quantity of electrical and electronic equipment waste reused and recycled in the period 2010-2030 (kg/inhabitant)

Country	2010	2018	2025	2030
Belgium	7.77	8.77	9.16	9.59
Bulgaria	4.77	6.07	8.12	9.59
The Czech Republic	4.39	7.42	11.88	14.54
Denmark	12.49	9.92	7.41	5.67
Germany	7.86	8.80	8.99	9.35
Estonia	3.50	6.49	9.22	11.17
Ireland	7.83	10.69	15.65	19.32
Greece	4.10	4.36	6.25	7.60
Spain	2.29	5.91	8.38	10.45
France	5.18	9.03	8.61	8.31
Croatia	N/A	9.26	17.65	23.48
Italy	8.47	5.87	2.09	0.24
Cyprus	2.25	3.45	4.74	5.60
Latvia	1.73	4.25	6.07	7.37
Lithuania	2.09	4.15	6.70	8.07
Luxembourg	8.15	8.78	6.81	5.40
Hungary	3.34	5.97	7.59	8.74
Malta	2.09	4.82	7.20	8.77
Netherlands	6.16	8.09	10.07	11.53
Austria	7.10	10.51	13.12	14.98
Poland	2.31	5.90	8.17	10.06
Portugal	3.75	5.23	6.98	8.05
Romania	1.10	2.72	6.83	9.77
Slovenia	3.32	5.48	7.40	8.96
Slovakia	3.54	5.20	6.65	7.69
Finland	8.39	10.84	12.91	14.35
Sweden	14.45	11.82	9.71	7.96
EU-27	5.65	7.30	8.74	9.78

The results on the evolution of the amount of electrical and electronic waste electrical equipment reused and recycled during the period 2019-2030 are presented in Table no. 5. As with the previous indicators, an increasing trend can be observed for waste reused and recycled at the EU Member State level. Therefore, compared to 2018, the average amount of reused and recycled electrical and electronic waste is expected to increase by 19.63% by 2025 and by 33.97% by 2030.

As indicated by the previous indicators, there are a number of Member States that have performed above the European average in terms of the amount of electrical and electronic waste reused and recycled. Thus, the analysis carried out showed that the Czech Republic (+95.96%), Ireland (+80.73%), and Malta (+81.95%) were among the top performers. This time also, the research highlighted Romania's evolution as spectacular in relative terms, with a projected growth of +259.19% during the period 2018-2030, but the very high growth rate is due to the extremely low amount of electrical and electronic waste collected in the baseline

period, well below the European average during the same period. Regarding the countries with an estimated relative decrease in the amount of electrical and electronic waste reused and recycled, we can mention Denmark (-42.84%), France (-7.97%), Italy (-95.91%), Luxembourg (-38.50%) and Sweden (-32.66%). Thus, the EU countries that performed strongly in 2018 and are expected to maintain the same high performance in 2030 are the Czech Republic, Ireland, Croatia, the Netherlands, Austria and Finland.

The research also highlighted a relevant number of EU countries that have made a significant leap in increasing performance in the reuse and recycling of waste electrical and electronic equipment. Estonia, Spain, and Poland are the three European countries that performed below the EU average in 2018, but it is expected that if the same trend continues over the period analyzed, they will maintain higher values than the EU average by 2030.

The results obtained are in line with those published by Zlamparet et al. (2015) who compared the waste management system of EEE in Bucharest (Romania) and Beijing (China) and observed that, by encouraging sustainable consumption, the separate WEEE collection improved. To support the positive results obtained, mention can also be made of studies published by Awasthi et al. (2018), which reveal the presence of a strong linear correlation between overall e-waste generation and GDP, and Otto et al. (2018), which argue that costly structural improvements can be overcome by e-waste collection campaigns that address social reasons.

Regarding the evolution of the recycling rate of electrical and electronic waste equipment in the period 2019-2030, the research results are summarized in Table no. 6. Therefore, it can be noted that the average values of this indicator at the EU level are on a steady upward trend, starting from an average collection rate of 38.90% in 2018 and reaching an estimated average collected value in 2030 of 55.40%.

**Table no. 6. Evolution of the recycling rate of electrical and electronic waste
in the period 2010-2030 (percentage)**

Country	2010	2018	2025	2030
Belgium	30.40	39.30	44.44	49.16
Bulgaria	40.80	66.70	100.0 ^b	100.0 ^b
The Czech Republic	22.70	43.60	61.89	74.95
Denmark	41.00	67.50	57.50	63.03
Germany	37.80	36.90	39.38	40.71
Estonia	30.30	53.70	75.51	91.56
Ireland	30.90	53.50	73.12	87.31
Greece	19.40	35.80	56.10	70.60
Spain	14.70	43.00	69.81	88.33
France	21.80	34.20	17.40	5.40
Croatia	N/A	83.40	100.0 ^b	100.0 ^b
Italy	27.80	30.48	33.00	34.80
Cyprus	11.50	39.93 ^f	100.0 ^b	100.0 ^b
Latvia	14.50	43.30	68.50	86.50
Lithuania	16.60	36.40	56.85	64.98
Luxembourg	33.00	44.10	34.30	27.30
Hungary	26.00	50.50	46.30	43.30
Malta	13.10	17.31 ^f	51.14	70.20

Country	2010	2018	2025	2030
Netherlands	27.80	41.00	58.48	68.83
Austria	35.70	46.00	55.25	61.86
Poland	17.70	39.10	59.13	72.41
Portugal	22.80	49.25 ^f	70.71	86.10
Romania	12.00	27.64 ^f	47.50	60.00
Slovenia	22.00	33.60	52.87	63.64
Slovakia	34.90	45.80	58.13	65.24
Finland	28.70	49.20	66.47	78.68
Sweden	55.30	45.40	33.35	23.27
EU-27	27.90	38.90	48.53	55.40

^f prognosed values; ^b maximum prognosed.

Analyzing the results, we can identify a number of Member States with a growth rate significantly higher than the European average rate over the period 2018-2030, such as Greece (+97.12%), Cyprus (+150.44%), Latvia (+99.77%), Poland (+85.19%), Romania (+117.08%) and Slovenia (+89.40%). In this chapter, it is worth noting the spectacular growth rate forecast for Malta, which, although starting from the lowest collection rate in the EU in 2018 (17.31%), is expected to reach a collection rate of 70.20% in 2030, representing an increase of 305.55% over the period analyzed.

The research results also highlight a number of European countries that have performed above the EU average throughout the period analyzed, including Bulgaria, Estonia, Ireland, Croatia, Portugal, and Finland. It is clear that the estimated recycling rates of 100% in 2030 for some of the countries analyzed (Bulgaria, Croatia, or Cyprus) are highly unlikely to be achieved, but these estimates are a strong signal as to the direction in which they are heading, and the measures that have led to this strong upward trend could be used as an example of good practice for other European countries.

According to the results, if the current trend in the figures continues into the future, it is estimated that by 2030 just over half of the Member States (15 countries, i.e., Bulgaria, the Czech Republic, Estonia, Ireland, Greece, Spain, Croatia, Cyprus, Latvia, Malta, the Netherlands, Poland, Portugal, Slovakia and Finland) will reach the 65% recycling rate target. A possible solution to increase the recycling rate is mentioned by Shevchenko et al. (2019), who highlight the need to understand consumers' e-waste recycling behavior and suggest introducing new economic incentives to achieve higher recycling rates.

For a better understanding of the research results, see Figure no. 1 shows the development of indicators at the EU level during the period 2010-2030.

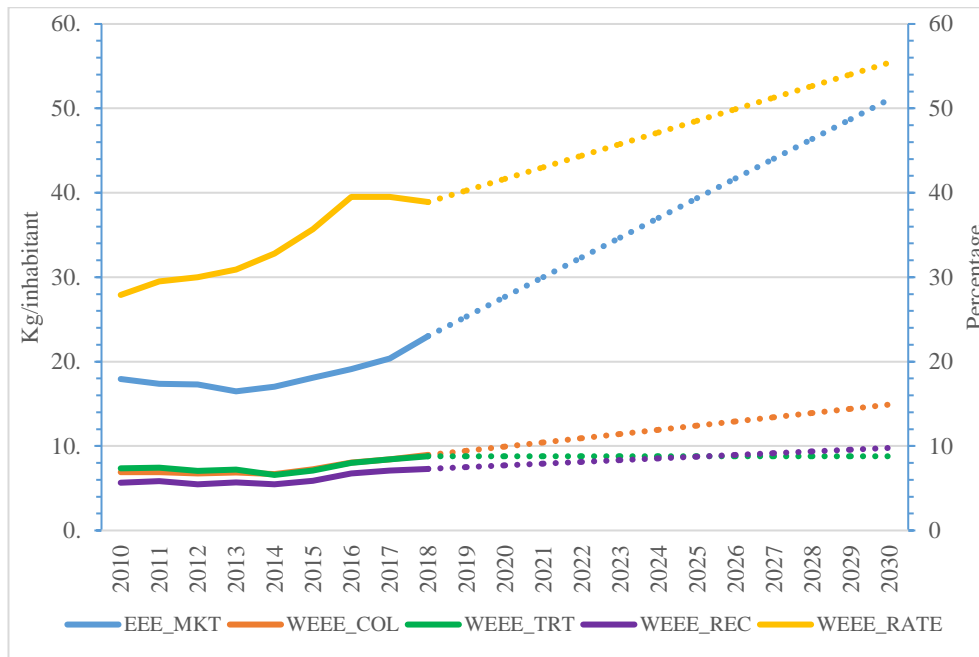


Figure no. 1. Development of indicators at the EU level over the period 2010-2030

Conclusions

The interest and participation of decision makers at the EU level in the collection of waste electrical and electronic equipment is growing, as the results of the analysis show.

In this regard, a number of relevant observations can be drawn from the evolution of the five indicators included in the analysis. For the period 2019-2030, the average amount of electrical and electronic equipment placed on the European Union market is expected to grow steadily, with a more than twofold increase in the year 2030 compared to 2018, reaching a predicted 117.64%. Alongside this increase in equipment put on the market, research results suggest an upward trend in the average amount of electrical and electronic waste collected and the average amount of waste treated.

The research results also suggest that by 2030 the average amount of reused and recycled WEEE is expected to increase by approximately 33.97%, while the recycling rate of WEEE is expected to increase by 55.40% by 2030.

The theoretical contribution of this study lies mainly in the fact that it provides a unique insight into the potential evolution of the values of the relevant indicators for the management of waste electrical and electronic equipment, but also provides relevant information on the dynamics of the adaptation of EU countries to the increasingly stringent requirements in the context of the transition towards a low-carbon and circular economy. Based on the research results, stakeholders can extract relevant information on the effectiveness of policies to support the transition to a circular economy, potential unfavorable developments can be

highlighted, and countries for which positive results are expected can be identified as examples of good practice at European level.

The research results also suggest a potential change in the behavior of consumers of electrical and electronic equipment toward the promotion of sound principles of responsible consumption, with an increased emphasis on reusing existing equipment, extending the life of use, or avoiding economically unjustified purchases. In this way, a reduction in waste collected and treated can be achieved with positive effects on the environment and on people. These observations can be highly relevant for the management of companies in the sector, but they can also provide a solid basis for establishing public policies or specific initiatives to better support the promotion of responsible consumption of electrical and electronic equipment, especially in countries where less positive developments are anticipated.

In conducting the study, we faced certain limitations related to accessing the most recent data, given that the availability of statistical information on electrical and electronic waste was limited to 2018 at the latest. In terms of research methodology, the use of time series forecasting models implies the existence of confidence intervals, with the accuracy of the model decreasing as the number of forecast periods increases, which is reflected in higher uncertainty regarding the results obtained. At the same time, economic, social, or political factors can significantly influence the forecast results over medium and long time intervals.

In terms of potential future developments, the authors propose to extend their research by aiming at an analysis of the dynamics of electronic waste and recycling rates according to the urban-rural delimitation. We believe that the two environments may present interesting characteristics relevant to the subject matter, given a number of influencing elements, such as population density, income levels, age distribution of the population, as well as various aspects of purchasing behavior or social norms.

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