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Relationship Between Economic Security and Waste Processing Levels Among EU Countries

O. Khadzhynova
Sustainable Innovations Laboratory, Mykolas Romeris University,
Ateities g. 20, 08303, Vilnius, Lithuania

E-mail: azsudcom@gmail.com

Abstract. The article explores the relationship between economic security and the dynamics of waste processing among various groups in EU countries. The analysis of waste processing dynamics among EU countries was conducted both from the perspective of the type of processing (Energy recovery, Recycling) and from the perspective of the type of waste generation (recyclable wastes, mixed ordinary wastes, animal and mixed food waste, chemical and medical wastes). In addition, significant attention was paid to determining the relationship between the level of economic development and waste processing nationally among different EU countries. Using regression models, the magnitude of the average marginal impact of the level of economic growth on waste processing volumes among EU countries was determined.

1. Introduction

As urbanization and industrialization intensify, the waste management challenge becomes increasingly critical in the modern age. With its rich tapestry of nations and diverse economies, Europe has always been at the forefront of environmental concerns, with the European Union (EU) continually striving to set benchmarks in sustainability practices. One of the most palpable indicators of a nation's sustainability commitment is its waste recycling efficiency. This process mitigates environmental degradation and holds the potential for economic rejuvenation through the circular economy. Despite the advancements in understanding the relationship between economic security and waste processing levels among EU countries, there is a consensus in the literature that further development and nuanced research are required.

Babenko et al. (2020) shed light on the potential of renewable energy in Ukraine and Chile, drawing parallels to the EU's challenges and aspirations. The exploration of energy dynamics by Khadjynova et al. (2023) underscores the intricate ties between energy consumption dynamics within the EU and the broader implications for economic security. Koval et al. (2022) add to this discourse by emphasizing the role of the European Energy Partnership in harnessing sustainable energy potential, illustrating the interconnectedness of energy policies, waste management, and regional economic stability.

The policy landscape within the EU and globally emerges as a pivotal area of focus in the literature. Mazzanti and Zoboli (2008) critically assess the effectiveness of EU policies in addressing waste generation and disposal, hinting at the need for a decoupled economic approach. This notion is complemented by the European Commission's vision (2018) for a Circular Economy, advocating systemic shifts in waste management practices. The EEA's report (2017) on circular product design further amplifies this perspective, underscoring the importance of holistic sustainability considerations in product lifecycles.

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Technological innovations are also at the forefront of the literature. Rada et al. (2013) emphasize the transformative potential of Web-GIS systems in optimizing municipal waste collection across diverse economies. Similarly, Montejo et al. (2013) provide insights into the efficacy of mechanical-biological treatments, while Comăniță et al. (2015) address the mounting challenges posed by discarded electronic devices, with a specific focus on the Romanian context.
Broader environmental technology discussions are encapsulated by the works of Bianchi et al. (2021) and Eckelman & Graedel (2017), who respectively examine waste electrical and electronic equipment and the environmental implications of silver emissions. Their research points to the challenges and opportunities inherent in waste management through innovative technologies.
On a global scale, publications such as the World Bank's comprehensive snapshot (2018) of solid waste management up to 2050 provide a broader context. This is complemented by the insights of Balland & Boschma (2021) on technological diversification's potential in European regions, stressing the pivotal role of scientific capabilities.
In synthesis, the reviewed literature underscores the multifaceted challenges and opportunities at the intersection of economic security and waste processing within the EU, suggesting the need for more nuanced research and innovative solutions. These are the pivotal questions this paper seeks to address.
This study delves deep into the relationship between the economic development of EU countries, as indicated by their GDP per capita, and their waste recycling efficiencies. Analyzing data from 2010 to 2020, we aim to discern patterns, progressions, and potential areas of concern in this crucial intersection of economics and the environment.
In doing so, we aim to provide policymakers, environmentalists, and economists with insights that could shape future strategies and initiatives in the EU's waste management domain.
In the subsequent sections, we will present our research methodologies, findings, and analyses. Through rigorous data interpretation, we endeavour to unravel the complex dynamics of economic development and its influence.

2. Material and methods

Understanding the relationship between EU countries' economic progression and waste recycling efficiencies required a rigorous and multifaceted analytical approach. The foundation of our research lies in the official datasets procured from EU databases and related reports. The data from 2010 to 2020 provided an in-depth view of the waste recycling practices across the EU member states, represented in kilograms per capita, juxtaposed against their GDP per capita figures in US dollars.
The primary approach began with visually exploring the data across the mentioned decade. Line diagrams offered a glimpse into the trends, indicating the trajectories of recycling efficiencies over time. These plots helped discern patterns, shifts, and potential anomalies within the data, setting the stage for deeper analysis. Additionally, bar plots gave a comparative view of recycling efficiencies across different member states, highlighting variations, successes, and areas requiring more attention. When necessary, combination plots were also employed, overlaying multiple data layers for enriched insights.
The linear regression analysis then served as our central investigative tool. Aimed at discerning the intricate relationships between GDP per capita and waste recycling efficiencies, it quantified this relationship's strength and direction. The coefficient of determination became the key metric in understanding how much of the variance in recycling efficiency could be attributed to changes in GDP per capita. Furthermore, the Student's t-test assessed the significance of the regression coefficients, ensuring that our results were both statistically sound and contextually relevant.
Integral to the methodology was also the treatment and preparation of the data. Outliers, which could potentially skew results, were identified through boxplot analysis. Discrepancies were addressed promptly — either rectifying them or, if necessary, removing them from our analysis. In instances where the linear regression analysis demanded a more nuanced approach, data transformations were judiciously applied.

3. Theory/calculation

Waste processing, generated by various sectors of the national economy, is one of the primary factors ensuring social security, particularly ecological safety. Within the EU, two primary types of waste processing stand out: waste-to-energy conversion and recycling.

As indicated in Figure 1, approximately 200 million tons of waste are processed annually in the EU for recycling purposes. Figure1 shows a linear trend that can be discerned from 2010 to 2020 towards an increase in waste recycling, averaging 3.7 million tons yearly. In contrast, waste processing with the aim of energy resource generation significantly lags, increasing from 70 million tons in 2010 to almost 100 million tons annually by 2020. The notably lower volumes of waste-to-energy processing compared to recycling could be attributed to the European Union's emphasis on developing renewable energy and enhancing energy consumption efficiency, which almost has zero associated or secondary pollutant emissions, unlike waste processing for energy resource generation.

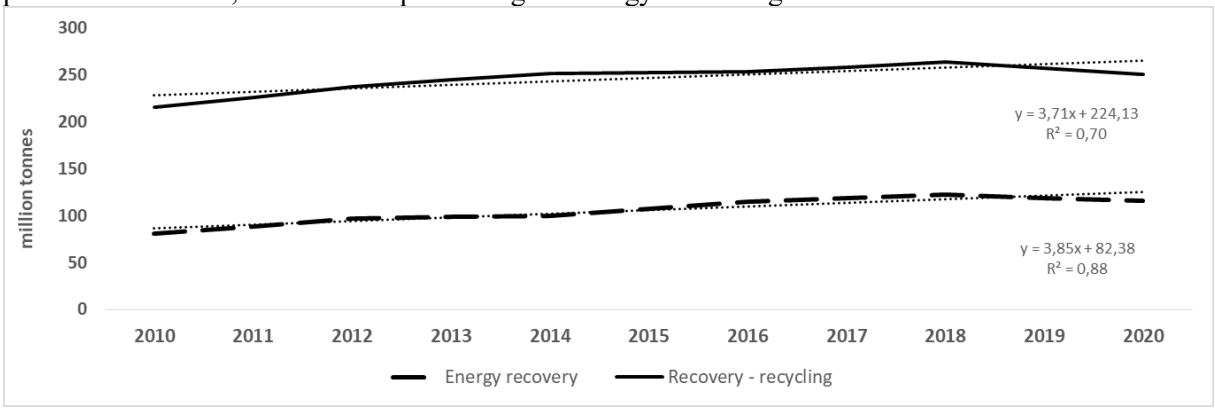


Figure 1. Primary Types of Waste Processing in the EU

According to Figure 2, four main types of waste are identified in the EU:

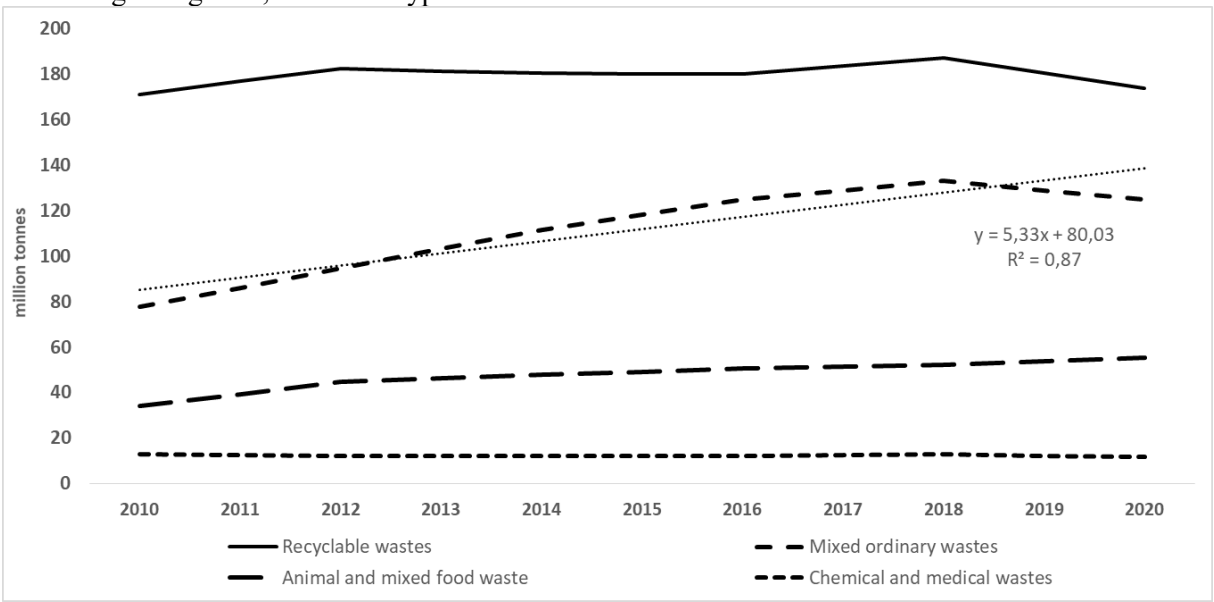


Figure 2. Main Types of Waste Processed in the EU

According to Figure 2, there are four main types of waste in the EU. The most significant type is recyclable waste, with about 160 million tons processed annually in the EU, and there has yet to be a discernible trend for growth or decline in this metric since 2010. The next volume is mixed ordinary wastes, whose processing has increased on average by 5.33 million tons since 2010, totalling over 120 million tons annually by 2021. The third largest is waste from the agricultural and food sectors (animal and mixed food waste), with its processing increasing from 30 to 50 million tons from 2010 to 2020.

The least processed are chemical and medical wastes, with a volume that has stayed the same over the last decade, remaining at about 15 million tons.
Examining waste processing in the EU in the context of the main types of waste, as seen in Figure 3, mixed ordinary wastes form the bulk of waste processed for energy recovery, increasing from 40 to 80 million tons from 2010 to 2020. A slightly lesser amount is recyclable waste. All other types of waste (animal and mixed food or chemical and medical) are hardly processed for energy resource recovery.

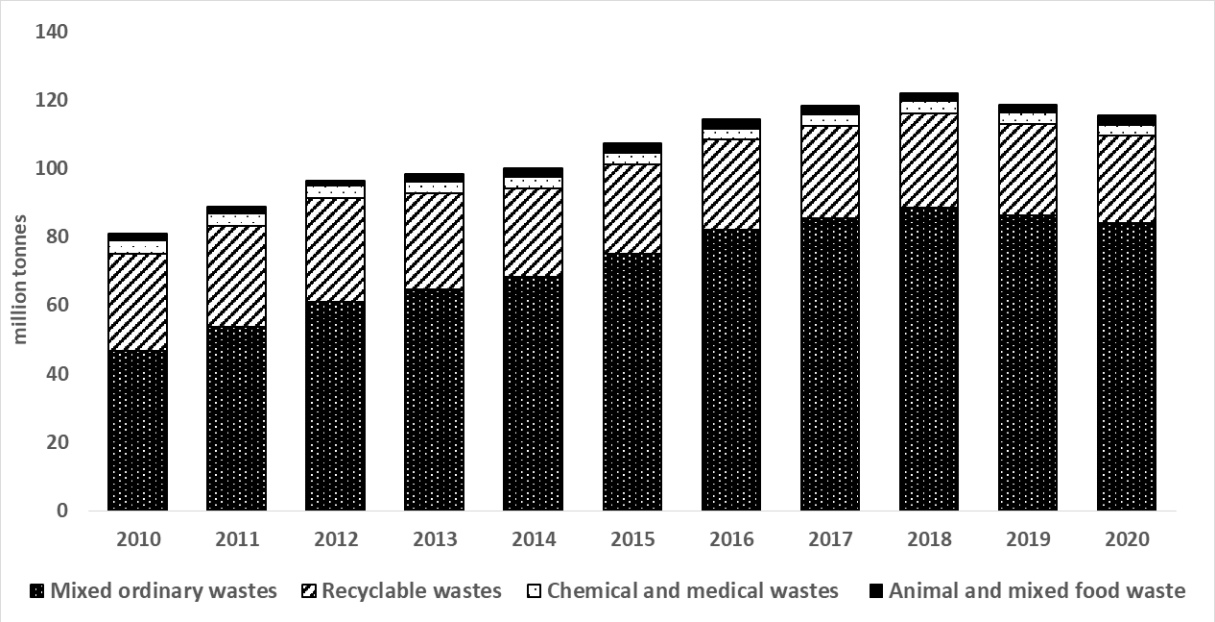


Figure 3. Energy Recovery in the EU
When analyzing the recycling process in the EU (Figure 4), recyclable wastes naturally dominate, making up over 50% of all recycling. In second place in the recycling structure are agricultural sector wastes, processed into fertilizers for the plant industry or feed for the animal industry. Mixed ordinary wastes come third.

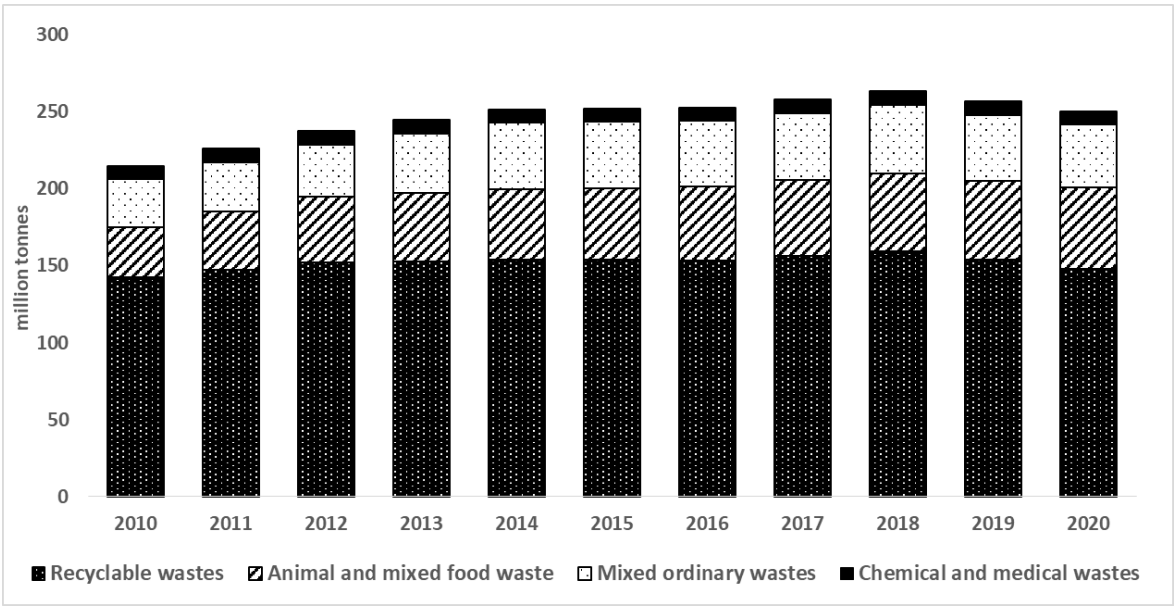


Figure 4. Recovery - Recycling in the EU

Considering the four types of waste processed among EU countries in more detail, Figure 5 dynamically presents recyclable wastes, mainly consisting of metallic iron wastes, wood, and paper

over the past decade. Wastes from glass, plastic, and non-ferrous metals form a significantly smaller but considerable volume. Throughout the analyzed period, none of the sub-types of recyclable wastes showed a trend of increase or decrease. This example (Figure 5) illustrates the importance of waste processing to the EU economy. For instance, the annual processing volume of metallic iron waste is about 50 million tons, while the average annual steel import to the EU is 11 million tons. This active recycling system allows for significant savings on this resource's import.

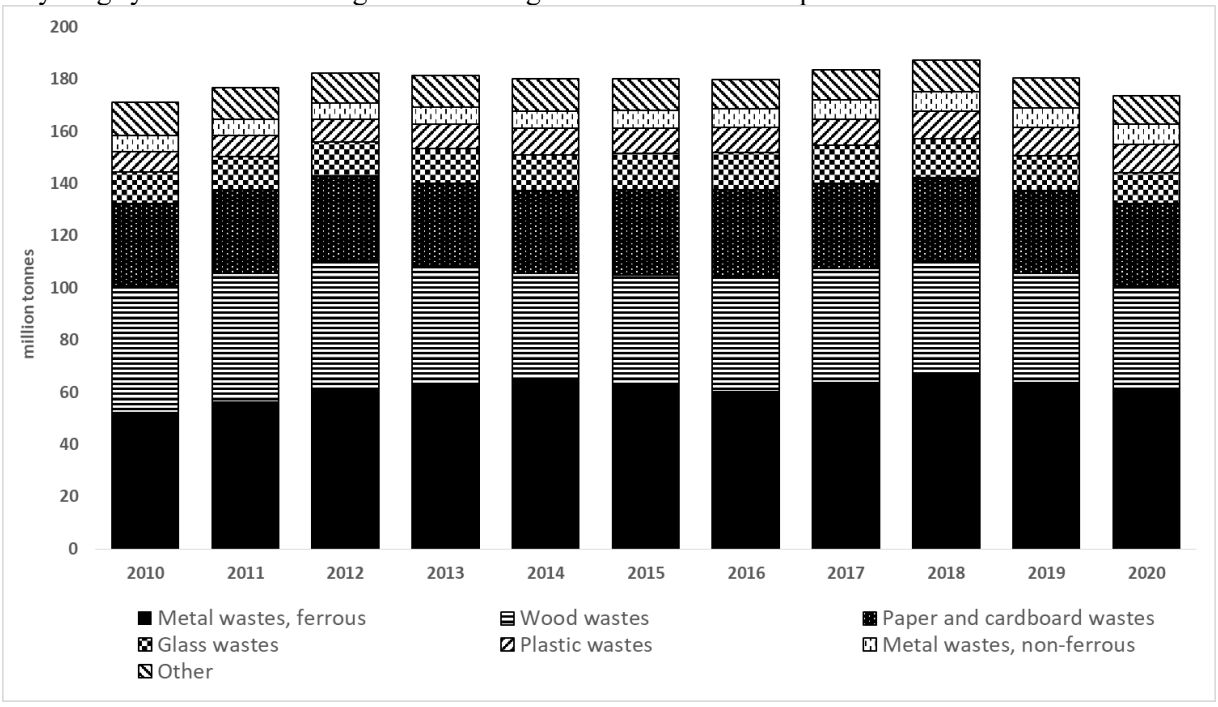


Figure 5. Detailed Examination of the Four Types of Waste Processed in the EU

The bulk of mixed ordinary wastes consists of household wastes and sorting residues (Figure 6). It is worth noting that since 2010, the amount of household waste that undergoes processing has increased by 20 million tons, while the recycling of sorting residues has increased by more than 40 million tons. The volumes of processing of other types of wastes that fall under the mixed ordinary wastes category have remained almost unchanged over the past decade.

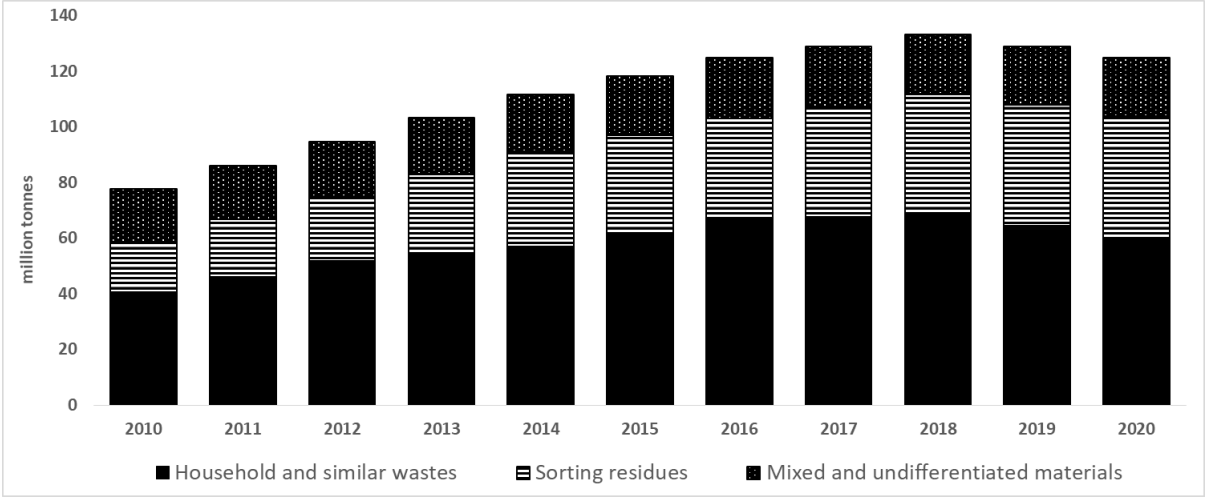


Figure 6. Mixed ordinary wastes in the EU

The central part of the waste of the agricultural complex of the EU (Figure 7) consists of plant waste (over 70%), the volume of recycling which from 2010 to 2020 increased from 27 to almost 50 million tons. The volume of animal waste recycling during the analyzed period has remained the same.

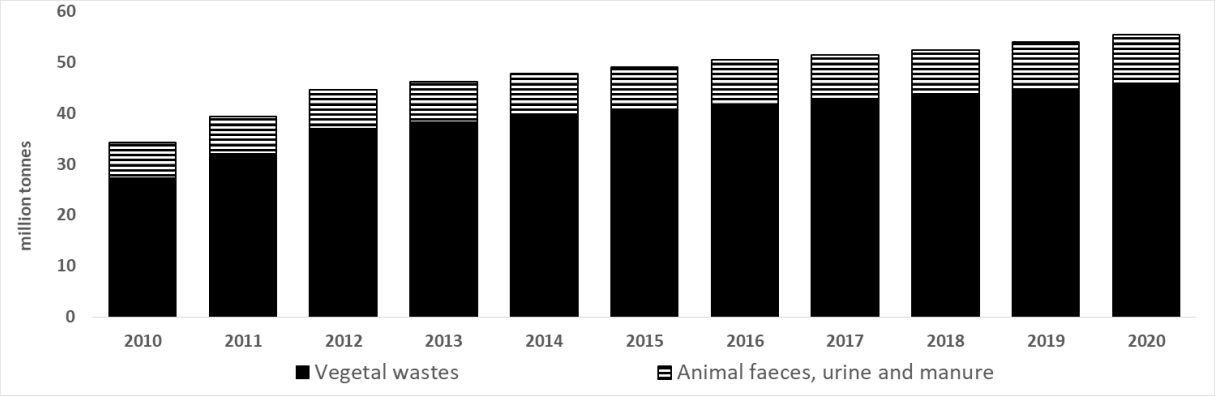


Figure 7. Animal and mixed food waste in the EU

The basis for recycling chemical and medical waste in the EU (Figure 8) consists of industrial effluents, acids, alkalis, and used lubricants. Recycling biological waste makes up the smallest part of this type of waste.

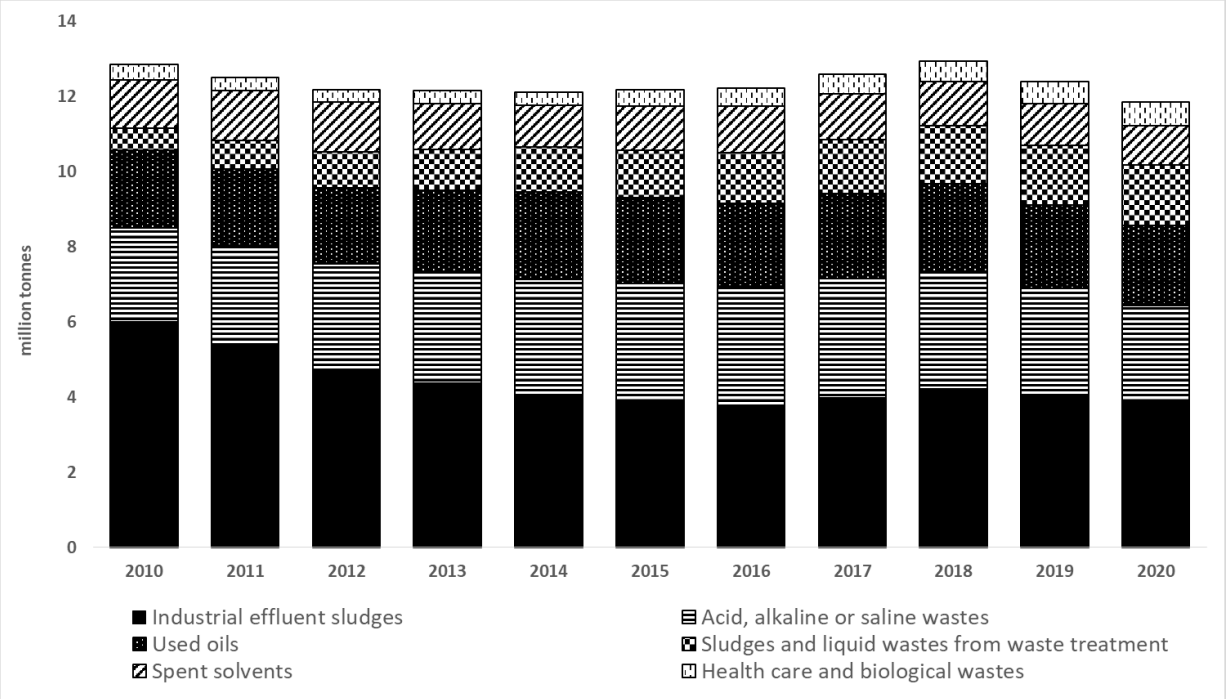


Figure 8. Chemical and medical wastes in the EU

When analyzing waste recycling among EU countries (Figure 9), the largest share is attributable to countries such as Germany, Italy, France, the Netherlands, Poland, and Spain. Moreover, if comparing the volumes of waste recycling in 2010 and 2020, almost all countries (except Finland and Denmark) showed an increase in this indicator. However, let us analyze the volumes of waste recycling among EU countries while simultaneously analyzing how much-recycled waste (tons) falls on 1 billion USD of a country's Gross Domestic Product (GDP). Almost all countries have roughly the same level of waste recycling efficiency, with an average value of 22.7 thousand tons per 1 billion USD GDP and a standard deviation of 11.6 thousand tons. Thus, for most EU countries, the volume of waste recycling largely depends not on the level of economic development but on the size of the national economy. Exceptions to this observation are countries such as Poland (42.9 thousand tons per 1 billion USD

GDP), Bulgaria (45.3 thousand tons per 1 billion USD GDP), or Luxembourg (39.4 thousand tons per 1 billion USD GDP). These countries have a lower nominal GDP than some other EU countries. However, at the same time, they demonstrate a higher level of waste recycling per 1 billion USD in GDP (compared to Germany, Italy, or France).

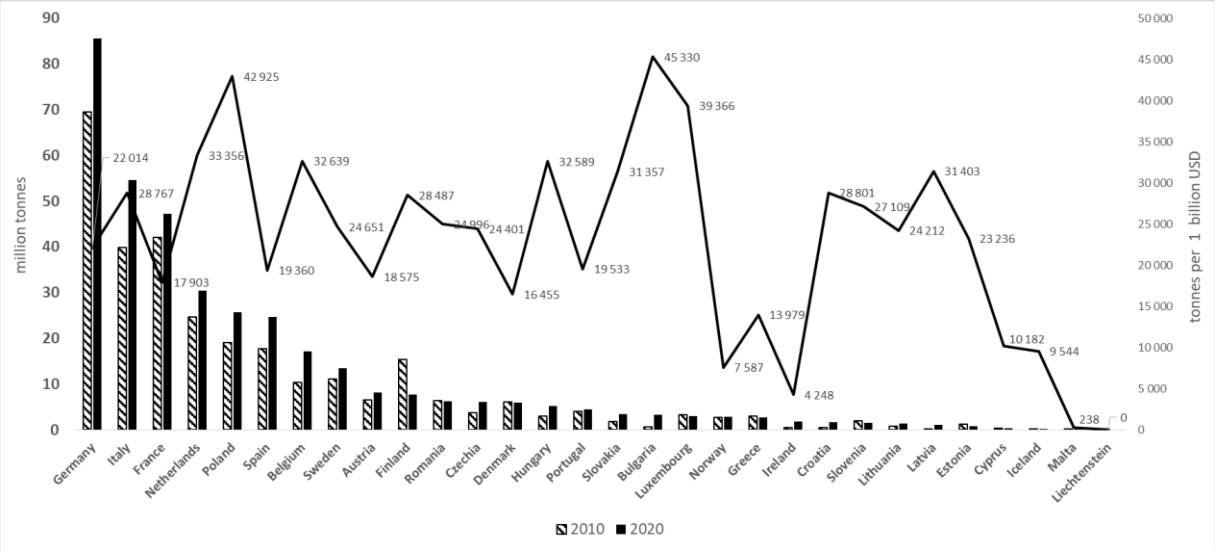


Figure 9. Volumes of waste recycling among EU countries in 2010 and 2020 (left) and volumes of waste recycling per unit of GDP among EU countries (right)

The previously advanced hypothesis that the volumes of recycled waste among EU countries directly depend on the nominal size of the Gross Domestic Product and not the level of economic development of the country (GDP per capita) can be confirmed based on Figure 10. If we construct a spatial regression dependence of the volume of recycled waste among EU countries depending on the nominal value of the Gross Domestic Product of the respective countries based on 2020 data, we get a regression model with a coefficient of determination of 94% and a marginal influence of GDP on waste recycling volumes of 0.0219 million tons, i.e., with an increase in the country's GDP by 1 billion USD - the volume of recycled waste increases by 0.0219 million tons.

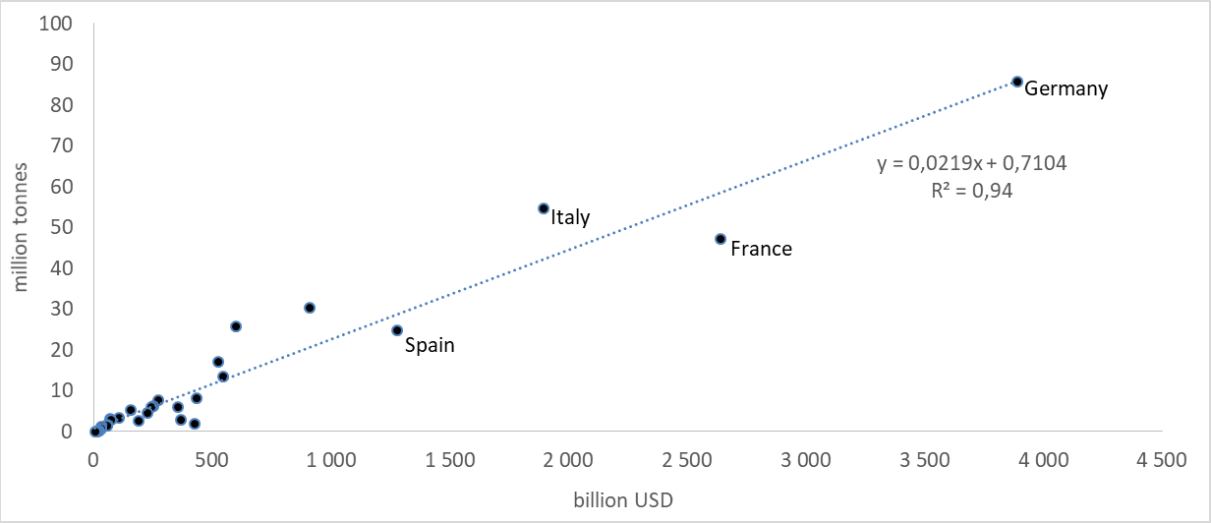


Figure 10. Scatter diagram of the volumes of recycled waste among EU countries depending on their Gross Domestic Product during 2020

It is prudent to analyze the waste recycling volumes among EU countries in the context of the economic development factor. Figure 11 presents a scatter plot illustrating the volume of waste

recycled per capita against the Gross Domestic Product (GDP) per capita for EU countries in 2020. As can be observed, a higher level of economic development in a country corresponds to a higher level of waste recycling. According to the calculated regression model (with a determination coefficient of 50%, indicating the presence of other factors influencing waste recycling levels among EU countries), the marginal effect is 0.0237 kilograms of waste per 1 USD per capita. This suggests that for every 1 USD increase in GDP per capita, waste recycling increases by 0.0237 kilograms per capita.

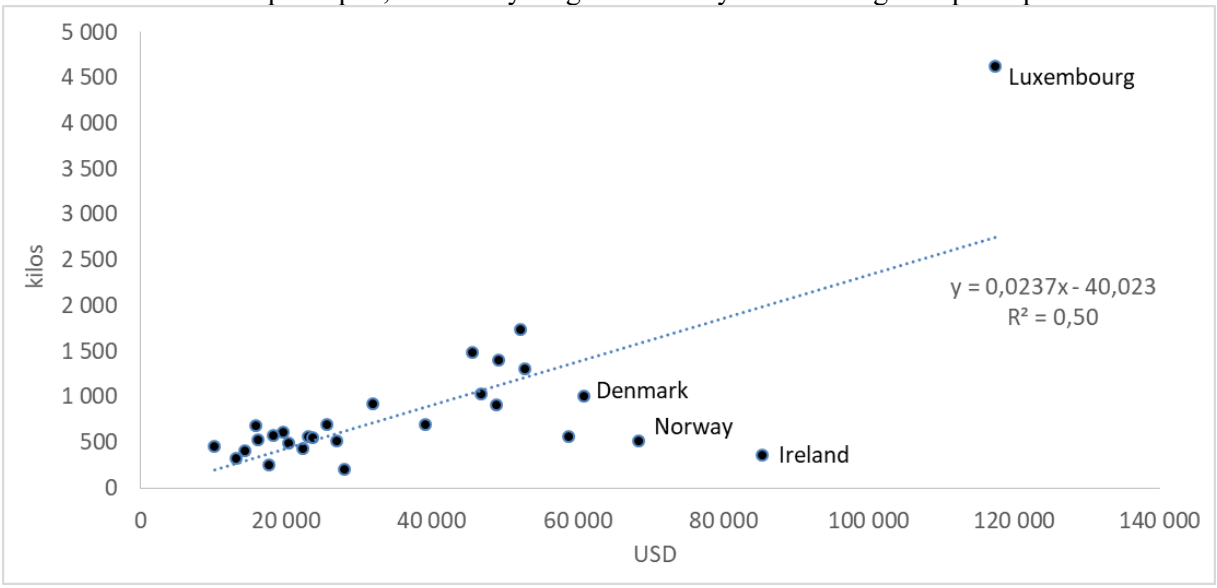


Figure 11. Scatter plot of waste recycling volume per capita against GDP per capita for EU countries based on 2020 data

Further examining the regression relationship of the annual volume of recycled waste against the annual GDP among EU countries for 2010 and 2020 (Table 1), we can see that the regression models for 2020 and 2010 have significant determination coefficients of 94% and 93%, respectively. The marginal GDP effect on the volume of recycled waste for both models is significant based on the Student's t-criterion at a significance level of less than 0.001. Compared to 2010, the marginal GDP effect on the volume of recycled waste for 2020 increased by 0.004 million tons, amounting to 0.022 million tons, indicating an enhancement in waste recycling efficiency among EU countries.

Table 1. Regression relationship of the annual volume of recycled waste against the annual Gross Domestic Product among EU countries

Year	N	Regression model	R^2	S	T_0	T_1	p_0	p_1
2020	30	$y = 0,71 + 0,022x_1$	0,94	4,9	0,7	20,6	0,5	1,8E-18
2010	30	$y = 0,68 + 0,018x_1$	0,93	4,3	0,7	18,9	0,5	1,8E-17

Where:

- y represents the annual volume of a country's recycled waste in a million tons.
- x1 represents the country's annual GDP in billion USD.

When analyzing the regression dependency of the quantity of recycled waste per capita against the Gross Domestic Product (GDP) per capita for EU countries based on data from 2020 and 2010, we obtain models with determination coefficients of 50% and 51%, respectively. This indicates the

presence of other factors, besides the level of economic development, that influence the efficiency of waste recycling among EU countries. The marginal effect of GDP per capita on the amount of waste recycled per capita is significant based on the Student's t-criterion at a significance level of less than 0.001. Regrettably, compared to 2010, the marginal effect of GDP per capita on the amount of waste recycled per capita decreased from 0.037 to 0.024 kilograms. This may suggest that waste recycling efficiency among the most economically developed EU countries has diminished over the past decade.

Table 2. Regression relationship of the quantity of recycled waste per capita against GDP per capita among EU countries

Year	N	Regression model	R^2	S	T_0	T_1	p_0	p_1
2020	28	$y = -40,02 + 0,024x_1$	0,50	598	0,2	5,1	0,85	2,4E-05
2010	28	$y = -433 + 0,037x_1$	0,51	889	1,5	5,2	0,16	2,1E-05

Where:

- y represents the annual volume of a country's recycled waste per person in kilograms.
- x1 represents the country's GDP per person in USD.

With every 1 USD increase in GDP per capita, recycled waste increases by 0.02 kilograms.

4. Results/Discussion

Our analysis of waste recycling within EU countries as influenced by their respective GDP per capita has produced some findings. The regression models derived from the 2010 and 2020 data exhibited 50% and 51% determination coefficients, respectively. This indicates that only about half of the variability in waste recycling efficiency can be attributed to differences in economic development among the studied countries. Such findings emphasize the multifaceted nature of waste recycling processes and their dependency on a myriad of factors, not just the economic robustness of a nation.

One of the more alarming revelations from our study is the evident decline in the marginal effect of GDP per capita on the amount of waste recycled per capita over a decade. While this might be interpreted as an indicator of diminishing efficiency in waste recycling, especially among economically developed EU nations, it also underscores the necessity for more comprehensive waste management strategies. Economic development alone cannot be the sole driver for efficient waste recycling.

5. Conclusion

The study has its limitations. Our focus was predominantly on the relationship between GDP per capita and waste recycling efficiency. This meant that our models did not account for other influential variables, such as socio-cultural factors, government policies, public awareness campaigns, technological advancements in recycling methods, or regional ecological initiatives. Such factors could provide a more comprehensive understanding of the dynamics of waste recycling.

There are some further research proposals:

1. Different regions within EU countries might have varied recycling rates influenced by regional policies, population density, and local awareness. Diving into a granular, regional analysis might unveil patterns not apparent nationally.
2. Understanding the socio-cultural dynamics of recycling can provide insights into public perception and behaviour towards waste management.
3. A study into the latest technological innovations in waste recycling in different countries might elucidate if technological disparity is a significant determinant.
4. A comprehensive examination of different EU countries' waste management policies can determine if specific policy components significantly impact recycling efficiency.

5. It would be worthwhile to investigate if nations with robust public awareness and educational campaigns about recycling have better recycling rates.

In conclusion, while our study has shed light on the intricate relationship between economic development and waste recycling efficiency among EU countries, it has paved the way for more profound, multifaceted research. A more holistic approach, factoring in various determinants, can provide a more precise roadmap for EU nations aiming to enhance their waste recycling efficiencies. It is imperative that as we march towards a future marked by sustainability challenges, our strategies for waste management become more nuanced, informed, and adaptive.

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