DOI: 10.47743/nextstepeu.2025-06

GREEN INVESTMENTS AND RECYCLABLE RAW MATERIALS: A BIDIRECTIONAL ELASTICITY ANALYSIS OF AUSTRIA, BULGARIA, FRANCE, POLAND, ROMANIA, SPAIN AND THE EU

GEORGE-CORNEL DUMITRESCU
The Institute for World Economy, The Romanian Academy
Bucharest, Romania
george.dumitrescu@iem.ro

Abstract
Using log-log linear regression models and quantitative analyses, the research focuses on the relationship between the environmental protection investments of the total economy (EPI) in million euros, and intra-EU imports of recyclable raw materials (IRRM), in tonnes. This analysis covers the EU as a whole and six member states: Austria, Bulgaria, France, Poland, Romania, and Spain, from 2014 to 2022, a period for which more extended time series were identified at Eurostat. The research also explores the dynamics of the selected indicators in the same time frame. Bidirectional relationships were employed via two sets of regressions: one with IRRM as the dependent variable and another with EPI as the dependent variable.
The results underscore heterogeneities across the selected countries and the EU aggregate. In the set where IRRM is the dependent variable, Austria exhibits a positive and statistically significant elasticity (0.12%), while France and Romania display significant negative elasticities (-0.26 and 0.49, respectively). In the inverse models, Bulgaria and the EU show significant positive elasticities (1.19% and 2.36%, respectively) from IRRM to EPI, whereas France and Romania exhibit negative elasticities (-2.2% and -1.29%).
For greater clarity, further research should focus on the root causes of these heterogeneities and provide tailor-made solutions to national strategies aimed at achieving open strategic autonomy.
Keywords: *environment; investments; recyclables; trade.*
JEL Classification: Q56, F18, C21

1. INTRODUCTION

To maintain its relevance on the global stage, the EU needs critical raw materials for its competitive economic sectors. During the COVID-19 pandemic, when the supply chains suffered because of the restrictions, the EU member states realised how dependent they are to foreign suppliers and realised the need to achieve open strategic autonomy (OSA). Strategic autonomy refers to the EU's capacity to act autonomously in strategically important policy areas, while open means that the EU encourages multilateral cooperation whenever possible and appropriate (Kroll, 2024).

According to Cagnin *et al.* (2021), it imports 71% of its need for phosphorus from Kazakhstan, 93% of magnesium from China, 68% of cobalt from Congo DRC, 64% of bauxite from Guinea, 78% of lithium from Chile, 98% of borates from Turkey, among others. These are critical raw materials for its industry to maintain a competitive advantage.

In this light, green investments, enhancing recycling capacities within the EU and trade in recyclable raw materials are important components of reaching OSA.

According to Eurostat (2025a), environmental protection encompasses all activities and actions that have as their primary goal the prevention, reduction, and elimination of pollution and environmental degradation.

Intra-EU27 imports of recyclable raw materials (IRRM) refer to the quantities of recyclable waste and scrap, as well as other secondary raw materials (by-products) that are shipped between EU Member States (Eurostat, 2025b).

This research aims to assess the potential impact of EPI on IRRM, providing decision-makers and other interested parties with a practical and updated tool for assessing their impact in the transition towards open strategic autonomy.

2. LITERATURE REVIEW

2.1. Economic incentives and trade in recyclables

Public regulation and fiscal incentives play an important role in promoting recycling and international trade in recyclable raw materials. Morici *et al*. (2022) argue that countries can benefit from increased trade opportunities by offering incentives for investment in recycling infrastructure, which leads to increased demand for recycled materials. Moreover, Egger and Keuschnigg (2024) argue that a resource-poor country could obtain gains regarding its trade terms and offset production distortions by launching a public innovation program for recycling technologies. Vercoulen *et al.* (2023) argue that penalising carbon-intensive processes could stimulate waste recycling. Therefore, combining support and penalising policies can improve decarbonisation. Carbon trading, a market-based approach to reducing greenhouse gas emissions, is one such policy. When carbon trading and investment in green technologies are in place, manufacturer recycling enhances both economic and environmental outcomes, as remanufactured products offer production cost savings (Li and Wang, 2023).

Price variability can impact investors' confidence in recycling and also the market stability. Moore *et al.* (2022) found a monthly standard deviation higher than 6% in the price of recyclables as compared to the price of primary raw materials.

2.2. Drivers of recycling and investments

Several factors stimulate recycling activities, including private investment, innovation, risk management and subsidies.

By employing a dynamic regression model, Lingaitienė and Burinskienė (2024) identified a statistically significant relationship between trade in recyclables and private investments in circular economy sectors, with no notable issues regarding autocorrelation and heteroscedasticity.

Lai *et al.* (2024) highlight that increasing rare earth recycling rates have economic benefits, including offsetting government subsidies and improving carbon trading valuations in the supply chain. They accentuate the importance of enterprise-focused research and development in improving the efficiency of closed-loop systems for rare earth elements.

He and An (2024) argue that rising subsidies and investments by manufacturers significantly enhance the participation of recyclers and customers in ethical trade-in programs. Additionally, Koval *et al.* (2023) argue that effective investment risk management is conducive to environmental investment activities regarding the transition to eco-friendly construction, reforestation, and raw material certification.

Moreover, Foggia and Beccarello (2023) emphasise the role of tax credit schemes in stimulating investments to reduce or prevent waste production as well as to improve the quantity and quality of sorted waste.

Nicolli *et al.* (2012) emphasise several market barriers or failures, such as information failures, consumption and technological externalities, which could lead to sub-optimal levels of recycling. However, as markets mature, these barriers may diminish, resulting in increased gains from trade.

2.2. Public policy and infrastructure

At the state level, Hotta *et al.* (2008) suggest that to establish a regional or international governance mechanism in waste and recycling, industrialised and urbanised countries should develop recycling capacity and mechanisms domestically. Jayasinghe *et al.* (2023) emphasise the importance of government participation in plastic waste management initiatives and the necessity for enhanced recycling infrastructure. Supporting this, Li *et al.* (2022) demonstrated that exporting ocean-sourced plastic waste to recycling-oriented countries can decrease water pollution by 9.4% and 91.7%, depending on the level of trade.

This paper analyses the uncharted relationship between total economy environmental protection investments and intra-EU imports of recyclable raw materials, emphasising the immediate effects through relevant econometric models across six EU countries.

3. METHODOLOGY

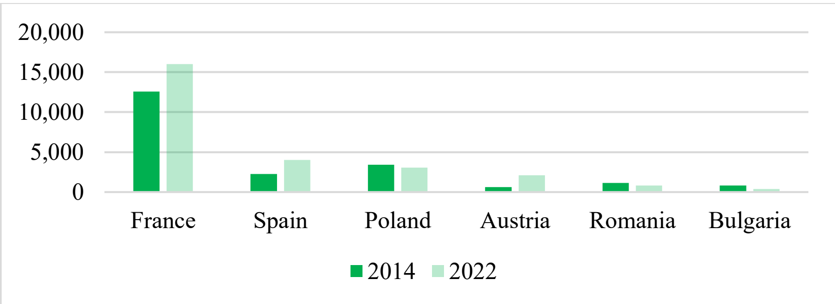
The data on EPI, and IRRM were extracted from the Eurostat database (Annexes 1 and 2). To obtain a more extended time series, we selected the EU, Romania, Bulgaria, Austria, France, Poland and Spain, countries for which data for both indicators were available between 2014 and 2022.

At first, we examined the dynamics of the selected indicators from 2014 to 2022 to determine their trends and better understand the econometric analysis results. We then employed ordinary least squares regression in Gretl based on the log-transformed IRRM as the dependent variable and the log-transformed EPI as the predictor to reveal how a 1% increase in EPI impacts IRRM as a percentage. We ran a second set of linear regressions where log-transformed IRRM, lagged by one or three years for the EU and Bulgaria, respectively, served as the independent variable, and log-transformed EPI was the dependent variable.

For statistically significant relationships at a 95% confidence level, we tested the linear regression assumptions of linearity (via Lagrange Multiplier tests), homoskedasticity (via White's tests), normality of residuals (via the Chi-square test), and absence of autocorrelation (via Breusch-Godfrey Lagrange multiplier tests and the Durbin-Watson statistic).

4. QUANTITATIVE ANALYSIS

Between 2014 and 2022, the EU's EPI increased by 28.31%, to almost 70 billion euros (Figure 1). In 2022, France ranked first in the EU, with investments of 16 billion euros, representing a 27.37% increase from 2014. In the rest of the countries in our selection, Spain ranked fifth (4 billion euros and an increase of 80%), Poland seventh (3 billion euros and a 10% decrease in the analysed period), Austria tenth (2 billion euros and a 230% increase), Romania fifteenth (820 million euros and a decline of 28%) and Bulgaria 21st (381 million euros and a decrease in EPI of 54%).



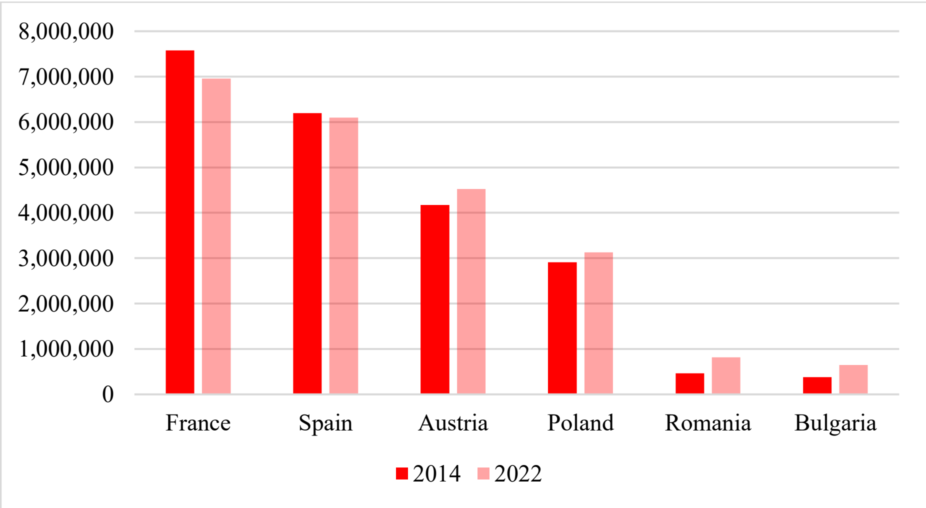
Source: author, based on Eurostat (2025a)

Figure 1. Environmental protection investments of the total economy, million euros

Regarding the dynamics during the first year of COVID-19 pandemic, with one exception, Bulgaria, which increased its EPI by 45%, the rest of the analysed countries registered declines: Austria 2%, France 9%, Poland 4%, Romania 9%, and Spain 3%, and the EU as a whole, 1%.

In the same period, the intra-EU27 imports of recyclable raw materials increased by 6% to 86 million tonnes.

In 2022, Germany was the leader in the EU in terms of imports, with 17 million tonnes and a 4% increase from 2014 (Eurostat, 2025b). In our selection, France ranked fifth with 7 million tonnes, a decrease of 8%, followed by Spain, which ranked sixth in the EU (6 million tonnes and a decrease of 2%), Austria, seventh (5 million tonnes and an advance of 8%). Poland ranked ninth with 3 million tonnes, representing an 8% increase. Romania ranked 19th with 869 thousand tonnes, experiencing the highest increase (77%) and Bulgaria, ranked 23rd with only 650 thousand tonnes and an acceleration of 72% (Figure 2).

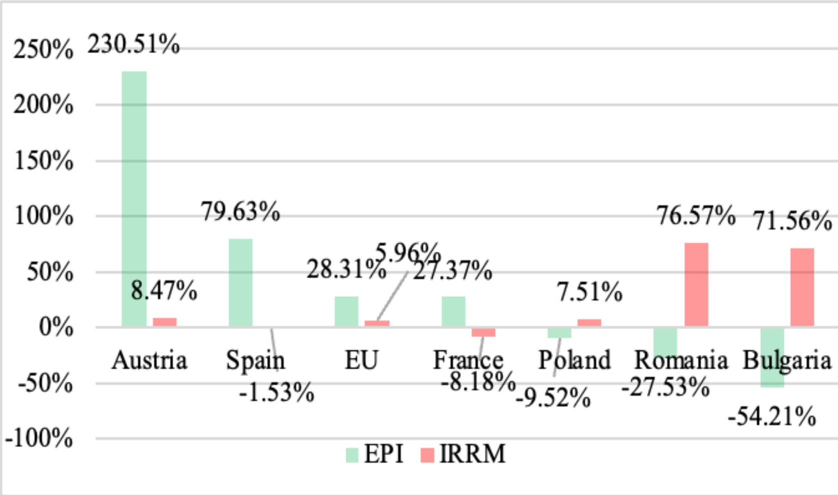


Source: author, based on Eurostat (2025b)

Figure 2. Intra-EU27 imports of recyclable raw materials, tonnes

In the first year of the pandemic, Austria was the only country in our selection that increased its IRRM (by 0.25%). In the remaining analysed countries, the imports decreased by 15% in Bulgaria, by 8% in Spain, by 6% in Romania, by 3% in Poland, and by 1% in France. Overall, in the EU, IRRM declined by 1%.

Regarding the percentage change between 2014 and 2022 (Figure 3), Austria registered the highest increase in EPI (230%), accompanied by an advance of IRRM of only 8%. Spain followed with an 80% expansion of EPI and a 2% decline in IRRM, and France was next, with an EPI growth of 28% and an 8% decline in IRRM.



Source: author, based on Eurostat (2025a; 2025 b)

Figure 3. Percentage change of EIP and IRRM between 2014 and 2022

The countries recording drops in EPI were Poland (-10% EPI and 8% increase in IRRM), Romania (-28% EPI and a significant increase in IRRM of 77%), and Bulgaria, with a decline of 54% in EPI, followed by an increase of 72% in IRRM.

5. ECONOMETRIC ANALYSIS

For Romania, we used the log EPI and the log IRRM. Under Gretl, we used the following steps: Model and Ordinary Least Squares. In the window (gretl: specify model), we selected l_EPI as the regressor, and the dependent variable was l_IRRM.

The model allowed us to estimate elasticity directly: a 1% change in EPI in year t results in a ß% change in IRRM in year t. The regression model results are displayed in Tables 1 and 2.

The linear relationship was tested at a 95% confidence level to see if it was statistically significant.

The null hypothesis (H_0) implies there was no statistically significant linear relationship between l_EPI_1 and l_IRRM in Romania. The alternate hypothesis (H_a) supported a statistically significant linear relationship between the two variables.

H_0: $\rho = 0$. H_a: $\rho \neq 0$.

The regression statistics are displayed in Table 1.

Table 1. OLS, using observations 2014-2022 (T = 9). Dependent variable: l_IRRM

	Coefficient	Std. Error	t-ratio	p-value
const	16.7514	0.946089	17.71	<0.0001
l_EPI	−0.485136	0.141869	−3.420	0.0111

Mean dependent var	13.52055	S.D. dependent var	0.227320
Sum squared resid	0.154799	S.E. of regression	0.148708
R-squared	0.625543	Adjusted R-squared	0.572049
F(1, 7)	11.69374	P-value(F)	0.011141
Log-likelihood	5.512380	Akaike criterion	−7.024759
Schwarz criterion	−6.630310	Hannan-Quinn	−7.875979
rho	−0.117019	Durbin-Watson	1.561658

Since the P-value = 0.0001, smaller than the significance level: $\alpha = 0.05$, the null hypothesis (H_0) is rejected (Table 1).

Therefore, we are 95% confident that a statistically significant linear relationship exists between l_EPI and l_IRRM in Romania.

Table 2. The results of tests to verify the assumptions

Lagrange Multiplier (LM) test for non-Linearity (squared terms), Null hypothesis: relationship is linear, $\alpha = 0.05$	Test statistic: LM = 0.590126 with p-value = P(Chi-square(1) > 0.590126) = 0.442371 p-value >α Relationship is linear
White's test for heteroskedasticity, Null hypothesis: heteroskedasticity not present, $\alpha = 0.05$	Test statistic: LM = 0.818639 with p-value = P(Chi-square(2) > 0.818639) = 0.664102 p-value >α Homoskedasticity
Test for normality of residuals, Null hypothesis: error is normally distributed, $\alpha = 0.05$	Test statistic: Chi-square(2) = 4.63388 with p-value = 0.0985749 p-value >α Error is normally distributed
Breusch-Godfrey test for autocorrelation up to order 3, Null hypothesis: no autocorrelation, $\alpha = 0.05$	Test statistic: LMF = 1.02982 with p-value = P(F(3, 4) > 1.02982) = 0.468857 p-value >α No autocorrelation
Estimated Equation of the regression line	$\text{Log}(IRRM_t)=16.756 - 0.485 \times \log(EPI_t)+ \varepsilon$

According to the model, in Romania, a 1% increase in EPI in year t is associated with a 0.49% decrease in IRRM in the same year. This inverse elasticity (Figure 4) may suggest that increasing recycling infrastructure via investments could reduce dependence on imported recyclables.

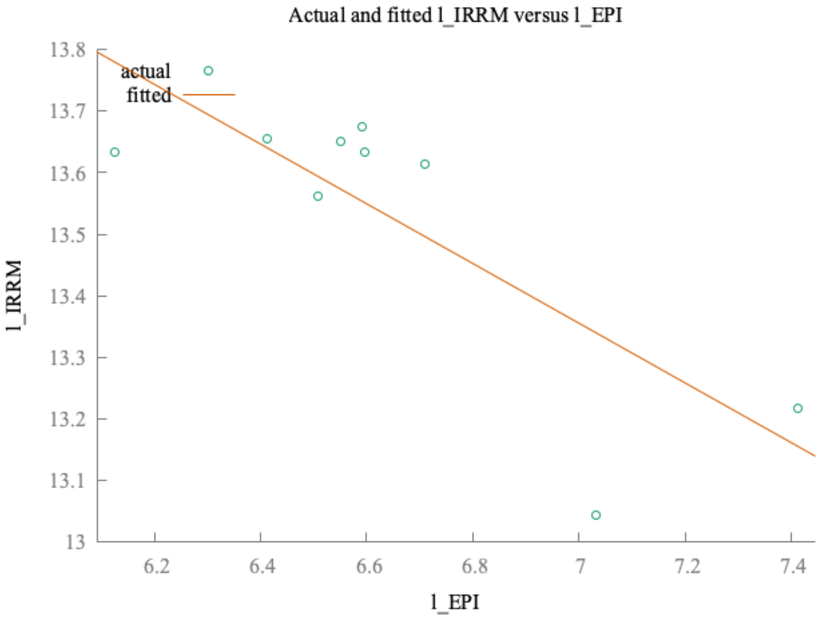


Figure 4. Actual and Predicted Log(GHG) in Romania Based on Lagged GFCF (2006–2022)

R-squared = 0.625543, suggesting that 63% of the variation in IRRM is explained by the relationship between the two selected variables.

The same methodology, with various procedures, was applied to the EU, as well as to Austria, Bulgaria, France, Poland and Spain, as shown in Tables 3 and 4.

Table 3. Summary table of linear regression statistical data for the countries where the relationship is not statistically significant

Country/ Indicators	EU	Bulgaria	Poland	Spain
R^2	0.309	0.286	0.339	0.108
P-value	P-value=0.210>α	P-value= 0.138>α	P-value= 0.100>α	P-value= 0.388>α
Intercept	16.107	14.176	14.219	15.006
Slope	0.196	−0.184	0.086	0.0787

The relationship is not statistically significant for the EU, Bulgaria, Poland and Spain, as the p-value is higher than the significance level (α = 0.05), as shown in Table 3.

Table 4. Summary table of linear regression statistical data and associated tests for the countries where the relationship is statistically significant

Country/ Indicators	Austria	France
R^2	0.573	0.563
P-value	P-value= 0.018<α	P-value=0.019<α
Intercept	14.471	18.238
Slope	0.121	−0.256
Statistical significance at a 95% confidence level	Yes	Yes
Durbin-Watson	2.353251	1.481420
Lagrange Multiplier (LM) test for non-Linearity (squared terms) Null hypothesis: relationship is linear, α=0,05	Test statistic: LM = 0.136584 with p-value = P(Chi-square(1) > 0.136584) = 0.711701 Relationship is linear	Test statistic: LM = 7.22248e-07 with p-value = P(Chi-square(1) > 7.22248e-07) = 0.999322 p-value >α Relationship is linear
White's test for heteroskedasticity, Null hypothesis: heteroskedasticity not present, α=0,05	Test statistic: LM Test statistic: LM = 5.27116 with p-value = P(Chi-square(2) > 5.27116) = 0.0716775 p-value >α Homoskedasticity	Test statistic: LM = 1.68573 with p-value = P(Chi-square(2) > 1.68573) = 0.430476 p-value >α Homoskedasticity
Test for normality of residuals, Null hypothesis: error is normally distributed, α=0,05	Test statistic: Chi-square(2) = 0.0367913 with p-value = 0.981773-value >α Error is normally distributed	Test statistic: Chi-square(2) = 1.67746 with p-value = 0.432258 p-value >α Error is normally distributed
Breusch-Godfrey test for autocorrelation up to order 3, Null hypothesis: no autocorrelation, α=0,05	Test statistic: LMF = 0.408515 with p-value = P(F(3, 4) > 0.408515) = 0.75601 p-value >α No autocorrelation	Test statistic: Chi-square(2) = 1.67746 with p-value = 0.432258 p-value >α No autocorrelation
Equation of the linear regression line	$\text{Log}(IRRM_t)=14.47 + 0.12 \times \log(EPI_t)+ \varepsilon$	$\text{Log}(IRRM_t)=18.24 - 0.256 \times \log(EPI_t)+ \varepsilon$

The models for Austria and France indicate a statistically significant relationship between the log-transformed data on environmental protection investments of the total economy and imports of recyclable raw materials (Table 4).

Austria: A 1% increase in EPI is associated with a 0.12% *increase* in IRRM. All the assumptions of linear regression were met. The value of R-squared indicates that 57.3% of the variation in IRRM can be explained by the relationship between the two variables. The model is robust and reliable with moderate explanatory power. The positive relationship indicates that an increase in EPI is accompanied by a corresponding increase in IRRM.

France: A 1% increase in EPI is associated with a 0.26% decrease in IRRM. All the assumptions of linear regression were met. Approximately 56.3% of the changes in IRRM can be attributed to the variation in EPI. The model is statistically robust and meets the assumptions of linear regression. While the Durbin-Watson statistic shows a slight autocorrelation, the performed tests confirm that it is not statistically significant.

We continued by analysing the inverse relationship where lnIRRM was the independent variable. For Austria, the model proved statistically significant, but it violated the assumption regarding the normality of residuals.

Table 5. Summary table of linear regression statistical data for the countries where the relationship is not valid

Country/ Indicators	Austria	Poland	Spain
R^2	0.572940	0.338782	0.107850
P-value	P-value=0.0182>α	P-value= 0.1001>α	P-value= 0.3882>α
Intercept	−65.6362	−50.6684	−13.5163
Slope	4.74396	3.92855	1.37033
Statistical significance at a 95% confidence level	Yes	No	No
Issue	Test for normality of residual - Null hypothesis: error is normally distributed Test statistic: Chi-square(2) = 6.68985 with p-value = 0.0352628 p-value<α Error is not normally distributed		

The relationship is not statistically significant for Poland and Spain, as the p-value is higher than the significance level (α = 0.05), as shown in Table 5.

The inverse models for Bulgaria, the EU, France and Romania exhibit statistically significant relationships at a 95% confidence level (Table 6).

Table 6. Summary table of linear regression statistical data and associated tests for the countries where the relationship is statistically significant

Country/ Indicators	Bulgaria (lnIRRM t-3)	EU (lnIRRM t-1)	France	Romania
R^2	0.694891	0.670201	0.563279	0.625543
P-value	P-value=0.0392<α	P-value=0.0130<α	P-value=0.0198<α	P-value= 0.0111<α
Intercept	−9.82629	−32.1784	44.2853	24.0932
Slope	1.19178	2.36424	−2.20103	−1.28942
Statistical significance at a 95% confidence level	Yes	Yes	Yes	Yes
Durbin-Watson	2.604871	1.773889	1.449746	2.283765
Lagrange Multiplier (LM) test for non-Linearity (squared terms) Null hypothesis: relationship is linear, α=0,05	Test statistic: LM = 0.290918 with p-value = P(Chi-square(1) > 0.290918) = 0.589633p-value >α Relationship is linear	Test statistic: LM = 0.436106 with p-value = P(Chi-square(1) > 0.436106) = 0.509008 p-value >α Relationship is linear	Test statistic: LM = 3.66356 with p-value = P(Chi-square(1) > 3.66356) = 0.0556147 p-value >α Relationship is linear	Test statistic: LM = 1.82474 with p-value = P(Chi-square(1) > 1.82474) = 0.17675 p-value >α Relationship is linear
White's test for heteroskedasticity, Null hypothesis: heteroskedasticity not present, α=0,05	Test statistic: LM = 3.08551 with p-value = P(Chi-square(2) > 3.08551) = 0.213791 p-value >α Homoskedasticity	Test statistic: LM = 1.38963 with p-value = P(Chi-square(2) > 1.38963) = 0.499168 p-value >α Homoskedasticity	Test statistic: LM = 0.569828 with p-value = P(Chi-square(2) > 0.569828) = 0.752079 p-value >α Homoskedasticity	Test statistic: LM = 2.33394 with p-value = P(Chi-square(2) > 2.33394) = 0.311309 p-value >α Homoskedasticity
Test for normality of residuals, Null hypothesis: error is normally distributed, α=0,05	Insufficient data to build frequency distribution for variable residual	Test statistic: Chi-square(2) = 1.93628 with p-value = 0.379789 p-value >α Error is normally distributed	Test statistic: Chi-square(2) = 2.3691 with p-value = 0.305884 p-value >α Error is normally distributed	Test statistic: Chi-square(2) = 0.762338 with p-value = 0.683062 p-value >α Error is normally distributed
Breusch-Godfrey test for autocorrelation up to order 3, Null hypothesis: no autocorrelation, α=0,05	Test statistic: LMF = 0.743727 with p-value = P(F(2, 2) > 0.743727) = 0.573484 p-value >α Insufficient degrees of freedom for regression up to order 3	Test statistic: LMF = 0.328162 with p-value = P(F(3, 3) > 0.328162) = 0.807713 p-value >α No autocorrelation	Test statistic: LMF = 0.162295 with p-value = P(F(3, 4) > 0.162295) = 0.916454 p-value >α No autocorrelation	Test statistic: LMF = 0.886349 with p-value = P(F(3, 4) > 0.886349) = 0.520311 p-value >α No autocorrelation

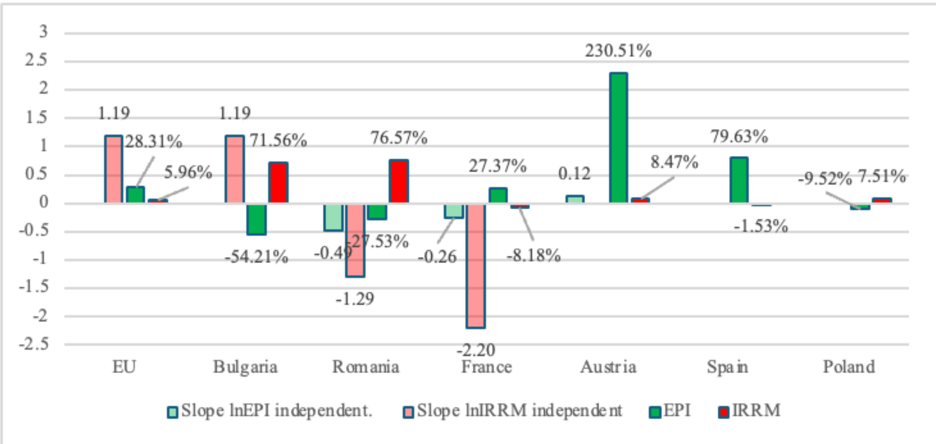
Country/ Indicators	Bulgaria (lnIRRM t-3)	EU (lnIRRM t-1)	France	Romania
	No autocorrelation			
Equation of the linear regression line	$\text{Log}(EPI_t)=-9.83 + 1.19 \times \log(IRRM_{t-3}) + \varepsilon$	$\text{Log}(EPI_t)=-32.18 + 2.36 \times \log(IRRM_{t-1}) + \varepsilon$	$\text{Log}(EPI_t)=44.29 - 2.20 \times \log(IRRM_t) + \varepsilon$	$\text{Log}(EPI_t)=24.09 - 1.29 \times \log(IRRM_t) + \varepsilon$

Bulgaria and the EU exhibit positive elasticities, suggesting that higher IRRM are accompanied by increases in EPI three or one year after, respectively.

In France and Romania, the relationship is negative, an increase in IRRM in year t being associated with a decrease in EPI in the same year.

6. INTERPRETATION OF THE RESULTS OF QUANTITATIVE AND BIDIRECTIONAL ECONOMETRIC ANALYSES

By considering both regression directions and the quantitative trends, we identified three relevant categories. The results highlight discrepancies across the analysed countries and the EU as a whole (Figure 5).



Source: author, based on Eurostat (2025a; 2025b)

Figure 5. Country results based on bidirectional EPI-IRRM elasticities and indicator dynamics, 2014 - 2022

Based on the dynamics of EPI (as the independent variable) and IRRM, four categories were identified:

(1) A negative EPI-IRRM relationship in both regression directions (substitution effect), indicating substitution dynamics: higher EPI reduce IRRM, and rising IRRM reduce the need for EPI.

In France, EPI and IRRM move in opposite directions, reflecting progress towards achieving open strategic autonomy through internal capacities.

Romania exhibits a similar elasticity pattern, driven by underinvestment and reliance on imports. The results indicate structural weaknesses and dependence, rather than autonomy, likely due to an inefficient recycling infrastructure that cannot transform enough waste into usable secondary raw materials.

(2) A positive unilateral EPI-IRRM relationship (infrastructure-driven, importer): In Austria, a high rise in EPI is accompanied by a significantly lower increase in IRRM, the tandem being supported by a positive elasticity (+0.12), likely due to a well-developed recycling infrastructure enabling a good integration into the intra-EU recyclables market.

(3) A positive unilateral IRRM-EPI relationship (IRRM-led investments) in the EU aggregate, where trade flows act as investment drivers.

In Bulgaria, the positive elasticity suggests that increased IRRM stimulate investments, with a delayed effect, possibly due to the insufficient recycling infrastructure or environmental pressures.

(4) Irrelevant models in Poland and Spain in any direction, requiring further investigation.

7. CONCLUSIONS

The research investigated the bidirectional relationship between environmental protection investments of the total economy and imports of recyclable raw materials, covering the EU and six member states from 2014 to 2022.

Bulgaria and the EU aggregate exhibited statistically significant positive elasticities in the model, with IRRM as the independent variable, indicating reactive investment patterns likely driven by recycling infrastructure demands.

Austria's positive elasticity in the model with EPI as the independent variable may indicate that increased investments stimulate intra-EU imports in countries with advanced recycling infrastructure and strong integration in the European market.

Conversely, the results for France and Romania exhibited statistically significant negative elasticities in both directions, indicating a substitutive effect between EPI and IRRM, with different structural backgrounds. France appears to be the closest to meeting the EU's goal of achieving open strategic autonomy, with increased investments leading to a reduction in imports.

These results highlight significant cross-country differences that may be related to the direction of analysis, recycling infrastructure, industrial demand, levels of investment, and the implementation of policies. They underscore that a uniform EU approach may not be effective across all member states, implying that tailor-made national policies that factor in local conditions (such as industry, recycling capacities, institutions and legislation) should be applied.

Further research should address these heterogeneities to provide decision-makers with more accurate tools for designing targeted, evidence-based policies tailored to the national context, to achieve open strategic autonomy.

References

1) Cagnin, C., Muench, S., Scapolo, F., Störmer, E. and Vesnic-Alujevic, L. (2021). *Shaping and securing the EU's open strategic autonomy by 2040 and beyond.* Luxembourg: Publications Office of the European Union. EUR 30802 EN. https://doi.org/10.2760/414963
2) Egger, P. and Keuschnigg, C. (2024). Resource dependence, recycling, and trade. *Journal of Environmental Economics and Management*, 128, p.103064. https://doi.org/10.1016/j.jeem.2024.103064
3) Eurostat (2025a). *Environmental protection investments of total economy*. [online] Available at: https://ec.europa.eu/eurostat/databrowser/view/env_ac_epite1__custom_13847640/default/table [Accessed 22.05.2025].
4) Eurostat (2025b). *Trade in recyclable raw materials*. [online] Available at: https://ec.europa.eu/eurostat/databrowser/view/cei_srm020__custom_13880170/default/table [Accessed 22.05.2025].
5) Foggia, G. and Beccarello, M. (2023). Sustainability pathways in European waste management for meeting circular economy goals. *Environmental Research Letters*, 18(12), p.124001. https://doi.org/10.1088/1748-9326/ad067f
6) He, C. and An, Q. (2024). Behavioral choice of manufacturers, recyclers and customers in trade-in programs. *PloS one*, 19(12), p.e0316344. https://doi.org/10.1371/journal.pone.0316344
7) Hotta, Y., Elder, M., Mori, H. and Tanaka, M. (2008). Policy considerations for establishing an environmentally sound regional material flow in East Asia. *The Journal of Environment & Development,* 17(1), pp. 26–50. https://doi.org/10.1177/1070496507312562
8) Jayasinghe, R., Attanayake, A., Liyanage, L., Bandara, N. and Sandaruwan, M. (2023). Exploring the plastic collection and recycling trends in Sri Lanka. *Recycling,* 8(6), 94. https://doi.org/10.3390/recycling8060094
9) Koval, V. V., Gonchar, V. V., Udovychenko, V. V., Kalinin, O. V., Slobodianiuk, O. V. and Soloviova, O. M. (2023). Risk management analysis of environmental investment in economic security. *Journal of Geology, Geography and Geoecology*, 32(3), pp. 540-549. https://doi.org/10.15421/112348
10) Kroll, H. (2024). *Assessing Open Strategic Autonomy*. Luxembourg: Publications Office of the European Union. https://doi.org/10.2760/767279
11) Lai, C., Wang, X., Li, H. and Zhou, Y. (2024). Unleashing the power of closed-loop supply chains: a Stackelberg game analysis of rare earth resources recycling. *Sustainability,* 16(12), p. 4899. https://doi.org/10.3390/su16124899
12) Li, D., Liu, C., Shi, Y., Song, J. and Zhang, Y. (2022). Trade flow optimization model for plastic pollution reduction. International *Journal of Environmental Research and Public Health,* 19(23), p. 15963. https://doi.org/10.3390/ijerph192315963

13) Li, M. and Wang, T. (2023). Recycling strategy of green closed-loop supply chain under urban and rural low-carbon planning. *Ecological Chemistry and Engineering S*, 30(4), pp. 595–615. https://doi.org/10.2478/eces-2023-0050
14) Lingaitienė, O. and Burinskienė, A. (2024). Development of trade in recyclable raw materials: transition to a circular economy. *Economies,* 12(2), p. 48. https://doi.org/10.3390/economies12020048
15) Moore, J., Folkinshteyn, D. and Howell, J. (2022). The potential for exchange-traded futures on recycled materials to improve recycling efficiency. *Investment Management and Financial Innovations,* 19(3), pp. 93–104. https://doi.org/10.21511/imfi.19(3).2022.09
16) Morici, E., Rizzarelli, P., Pibiri, M. C. and Montaudo, G. (2022). Recycled (bio)plastics and (bio)plastic composites: A trade opportunity in a green future. *Polymers,* 14(10), 2038. https://doi.org/10.3390/polym14102038
17) Nicolli, F., Johnstone, N. and Söderholm, P. (2012). Resolving failures in recycling markets: the role of technological innovation. *Environmental Economics and Policy Studies*, 14(3), pp. 261–288. https://doi.org/10.1007/s10018-012-0031-9
18) Vercoulen, P., Lee, S., Han, X., Zhang, W., Cho, Y. and Pang, J. (2023). Carbon-neutral steel production and its impact on the economies of China, Japan, and Korea: A simulation with E3ME-FTT: Steel. *Energies,* 16(11), p. 4498. https://doi.org/10.3390/en16114498

Annexes

Annex 1. Environmental protection investments of the total economy (EPI), million euros

Year	EU	Austria	Bulgaria	France	Poland	Romania	Spain
2014	54,400	635.5	833	12,560	3,405.2	1,131.6	2,247.1
2015	57,800	635.3	941.8	12,258.5	3,623.3	1,656.5	2,376.8
2016	48,300	705.2	282.1	11,860.8	1,493.7	609.2	2,100.4
2017	50,300	1,095.1	235.2	12,369.5	1,604	456.8	2,386.9
2018	55,343.3	1,386	255.1	12,950.3	2,387.6	699.7	2,691.1
2019	59,482.9	1,460.7	232.5	13,981.5	2,853.1	733.2	2,813
2020	58,723.3	1,430.5	336.5	12,702.3	2,726.1	670.8	2,717.5
2021	63,534.9	2,043.6	360.6	14,556.2	2,878.3	727.9	3,378.6
2022	69,800	2,100.4	381.4	15,998.2	3,081.1	820.1	4,036.4

Source: (Eurostat, 2025a)

Annex 2. Intra-EU27 imports of recyclable raw materials (IRRM), tonnes

Year	EU	Austria	Bulgaria	France	Poland	Romania	Spain
2014	81,582,768	4,174,835	378,148	7,579,915	2,912,716	462,764	6,192,742
2015	80,350,704	4,489,559	395,833	7,813,041	2,895,496	549,314	6,362,313
2016	81,237,097	4,016,358	434,165	7,484,796	2,697,733	851,389	5,830,657
2017	84,652,008	4,326,883	435,388	7,274,062	2,842,368	833,481	6,084,266
2018	85,389,506	4,629,289	496,328	7,274,894	3,106,736	848,653	5,870,234
2019	84,734,489	4,697,078	580,666	7,205,262	3,015,146	833,526	6,253,830
2020	83,055,931	4,708,635	492,509	7,283,222	2,924,311	776,484	5,754,159
2021	91,536,719	5,193,882	542,255	7,285,293	3,012,749	868,642	6,750,018
2022	86,441,301	4,528,444	648,737	6,959,975	3,131,550	817,107	6,097,720

Source: (Eurostat, 2025b)