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ECONOMIC DEVELOPMENT AND ECO-INNOVATION: AN ANALYSIS OF THE NON-LINEAR RELATIONSHIP IN THE EU-27

Nowadays, eco-innovation is considered the engine for a green path. This paper analyses the relationship between the level of economic development and eco-innovations for the EU-27 countries in the period 2013-2022. Results show an S-shaped curve in the relationship between the two variables in the EU countries: a lower level of GDP per capita implies that eco-innovation growth is monotonically positive or exponential, however, a higher level of economic development shows eco-innovation stagnates.

Desarrollo económico y ecoinnovación. Un análisis de la relación no lineal en la UE-27

Actualmente, la ecoinnovación es considerada como el motor para la transición verde. Este artículo analiza la relación entre el desarrollo económico y la ecoinnovación para la UE-27 en el periodo 2013-2022. Los resultados muestran una curva en forma de S en la relación entre ambas variables en estos países: un menor nivel de PIB per cápita implica que el crecimiento de la ecoinnovación es monotónicamente positivo o exponencial, sin embargo, un mayor nivel de desarrollo muestra que la ecoinnovación se estanca.

Keywords: *eco-innovation, GDP per capita, EU-27, non-linear relationship, S-shape.*
Palabras clave: *ecoinnovación, PIB per cápita, UE-27, relación no lineal, forma de S.*
JEL: *C13, Q55, Q56.*

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1. Introduction

The European Union (EU) recognizes that innovations play a crucial role in achieving its environmental objectives integrating it into the environmental action programmes and innovation policies to promote sustainable development.

The first time the environmental, innovation, and economic development aspects were brought together was in the Third Framework Programme for Research and Technological Development (1990-1994), which included a specific action on the environment and sustainable development (Council of the European Communities, 1990). Since then, several programmes analysing innovation and environmental objectives have been developed. In this sense, in 2011 the Eco-innovation Action Plan (European Commission, 2011) was created, and from this plan, eco-innovation has become a common approach in the following research and development framework programmes predicted until 2027 (Horizon 2020 and Horizon Europe). Therefore, eco-innovation is considered a key driver towards a greener and more sustainable economy (European Commission, 2011).

These EU's efforts have been aligned with the 2030 Agenda for Sustainable Development of the United Nations. Specifically, Sustainable Development Goal number 9 —SDG9— introduces the concept of eco-innovation as a way to modernize infrastructures and transform industries into sustainable ones, using resources more efficiently and promoting the adoption of clean and environmentally friendly technologies in industrial processes (SDG target 9.4). In addition, this SDG9 is coherent with the SDG13 of preserving the natural environment from the adverse effects of climate change (Szopik-Depczyńska *et al*., 2018). Therefore, the concepts of eco-innovation and economic development seem to be linked nowadays in economic, political, and social spheres.

However, while the relationship between economic development and eco-innovation has been scarcely analysed by now (Costantini *et al*., 2023; Zhu *et al*., 2023), there is a large body of literature that has studied the innovation-economic development binomial. Indeed, the relationship between general innovation and the level of development has been extensively analysed, beginning with exogenous (Solow, 1956) and endogenous growth models (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Romer, 1990), continuing with studies of the causality (Çetin, 2013; Maradana *et al*., 2017; Sadraoui *et al*., 2014; Sinha, 2008) and also going through analyses that examine the shape of the relationship between economic development and innovation (Dutta *et al*., 2022; Galindo Martín, 2008).

Based on the above, the motivation for this study is threefold. First, although there are many studies focusing on the relationship between Gross Domestic Product —GDP— per capita (in logarithms) and innovation, the shape of the curve has not been examined in depth. Second, the growing importance being given by the European Union to environmental goals and economic development makes it interesting to analyse these factors inside the EU group. Finally, joining the two previous motivations, it is of particular relevance to analyse the case of eco-innovation (a special type of innovation) and its relationship with GDP per capita within the EU, and specifically the shape of this connection.

Therefore, it is of interest to study this link when we add the green part of innovation, *i.e*., when it is considered eco-innovation. In this regard, the main research objective of this paper would be to add some empirical evidence to the analysis of the relationship between economic development and eco-innovation, studying particularly the shape of this relationship.

To satisfy our objective, we test the relationship between economic development and eco-innovation in the EU-27, using the eco-innovation scoreboard developed by the European Commission and the level of GDP per capita of the countries in the period from 2013 to 2022. In this sense, we analyse the statistical relationship between the variables, finding a non-linear relationship between them: an S-shaped curve, which shows a positive or exponential relationship between the GDP per capita and the eco-innovation level in low-income European countries;[1] while as the level of GDP per capita increases, the changes become smaller turning into a constant relationship.

Therefore, with this analysis, we contribute to the evidence of the shape of the curve by analysing the relationship between economic development and eco-innovation helping to draw some policy implications for the EU countries and also expanding them for other regions.

In this sense, it should be noted here that we focus on EU countries due to the data limitation for the measurement of eco-innovation in other economies. Similar results are expected to be obtained in other countries not included in the group of high income. These countries are likely, depending on their GDP per capita, to lie somewhere at the beginning of the S-shaped curve and once they reach a certain level of GDP per capita they are also likely to follow the path of the S-shaped curve. This would be an interesting future line of research.

Finally, the rest of the study is organized as follows: in the next section, we briefly collect the literature that supports the analysis; Section 3 describes in detail the data, methodology, and empirical results obtained in the study; and finally, Section 4 analyses the main conclusions.

2. Background

Economic Development and Innovation

The link between innovation and development was extensively studied in the second half of the 20th century, focusing mainly on exogenous and endogenous growth models (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Romer, 1990; Solow, 1956). Solow's (1956) growth model gave a central role to technology as a determinant of economic growth, as it drives long-term economic growth by enabling productivity improvements and overcoming diminishing returns to physical capital. It was not until the 1990s that innovation was considered an endogenous variable (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Romer, 1990). These models considered technology as a key driver of economic growth; and Research and Development —R&D— investment, human capital investment, government policies, and competition were the mechanisms through which technology was generated and diffused.

However, these same models indicated that economic development itself can also promote innovation. In this sense, Solow (1956) pointed out that economic growth can free up resources that can be allocated to innovation since long-term growth is influenced by an increase in total factor productivity that could allow for greater investment in R&D. In the same vein, Aghion and Howitt (1992) or Romer (1990) indicated that higher economic growth could increase investment in human capital and research, which in turn stimulates innovation. Therefore, a higher GDP is usually associated with a greater capacity to invest in R&D, infrastructures, and education, creating an environment favourable to the development of new technologies and knowledge. Thus, according to these models, innovation stimulates economic growth, and this, in turn, stimulates innovation, *i.e.*, there is a bidirectional relationship.

Based on the above, it is not surprising that studies have been carried out analysing the causality of the relationship between innovation and economic growth, empirically showing that economic development does, in fact, affect innovation (Çetin, 2013; Maradana *et al*., 2017; Sadraoui *et al*., 2014; Sinha, 2008). On the one hand, the studies by Çetin (2013) and Maradana *et al*. (2017) analyse such a link for European countries from the 1980s to the first decade of the 21st century. Both studies show that economic growth influences innovation depending on the country analysed. On the other hand, Sadraoui *et al*. (2014) chose a sample of

[1] We have divided the European Countries (EU) into Low Income EU and High Income EU. All the countries included here correspond to the classification of the World Bank of High Income Economies and Upper-middle Income Economies for the country of Bulgaria.

countries (32 countries) in the period 1970-2012 and concluded that economic growth has a relevant influence on R&D cooperation. Moreover, Sinha (2008) in his study of Japan and Korea, finds a bidirectional relationship between GDP growth and growth in the number of patents in the case of Japan. Therefore, empirical evidence also points out the influence of economic development on innovation, showing that the relationship is country-dependent.

Economic Development and Eco-Innovation

The term eco-innovation began to be used and gained prominence in discussions on sustainable development from the 1990s onwards. From the pioneer's studies in the last years of the '90s and beginning of the '00s decade, the analyses of eco-innovations have been focused mainly on the micro level (James, 1997; Kemp & Arundel, 1998; Kemp & Pearson, 2007). Specifically, these authors focused on how firms carried out innovations to improve environmental and resource efficiency.

Following these initial studies, the subsequent analyses were focused on the drivers at the firm's level which affect the development of eco-innovations. Technological push, Market pull, and Regulatory push-pull factors were identified as the main drivers in different samples around the world (Cuerva *et al*., 2014; De Marchi, 2012; Del Río *et al*., 2017; Fernández *et al*., 2021; Horbach, 2008; Horbach *et al*., 2012; Torrecillas *et al*., 2023; Triguero *et al*., 2013).

However, eco-innovation can also be studied at the macro level, as it was recognized in the different EU programmes —Horizon 2020, Horizon Europe, the European Green Deal, and the Next Generation funds—, which considered that eco-innovations play a key role in transforming the actual EU economy into a circular EU economy (Costantini *et al*., 2023). In this sense, eco-innovation can be defined as the engine for achieving the ultimate goal of sustainable development, increasing the efficiency and responsible use of natural resources and energy (Colombo *et al*., 2019).

Nevertheless, the analysis at the macro level has been scarce by now due in part to the limited availability of data for large periods. In fact, it was not until 2011 that the European Commission's Eco-innovation Action Plan was established (European Commission, 2011), which led to the publication of the Eco-innovation Scoreboard.[2] Since this year, several European reports and empirical evidence have been carried out at the macro level (Al-Ajlani *et al*., 2021; Barsoumian *et al*., 2011; Kemp *et al*., 2013), although authors are calling for more studies introducing the macro aspect of the eco-innovation (Chen *et al*., 2017).

Given the relevance of eco-innovation, it is not surprising that some of the studies at the country level have focused on analysing the relationship between indicators of the level of economic development —GDP per capita— and eco-innovations. Similar to the case of innovation, the linkage can be considered in both ways.

On the one hand, empirical evidence pointed out that eco-innovation positively affects economic growth and sustainable growth. This positive finding has been argued by Costantini *et al*. (2023) and Crespi *et al*. (2016). In addition, other authors have found a positive correlation between eco-innovation and GDP per capita (Pakulska, 2021) and more specific analyses have been carried out showing a similar relationship but for energy innovation (Ali *et al*., 2020).

On the other hand, the empirical evidence has also noted that a higher level of economic development affects positively the level of eco-innovations (Andabaka *et al*., 2019; Urbaniec, 2015). In fact, Andabaka *et al*. (2019) for a sample of European Countries and using the eco-innovation scoreboard indicator found this positive relationship. They indicated that economic development —GDP per capita— showed higher levels

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2 There are other approximations of Eco-Innovation used in the literature at the macro level as the Global Clean Tech Innovation Index (United Nations Industrial Development Organization —UNIDO—), which is elaborated from 2013 and incorporates more countries around the world. In addition, individual indicators have been also used as a proxy of Eco-Innovations as the environmental technology patents (OECD).

of eco-innovation, similar to what Pakulska (2021) noted. This argument has been also supported by Costantini *et al*. (2023). For their part, Urbaniec (2015) pointed out that eco-innovations were conditioned by its stimulus for the implementation, and at the same time, by the barriers which are country-dependent.

In this sense, considering that eco-innovation is a type of innovation, previous empirical evidence of growth models applied here, and therefore also its incentives and barriers: investment in R&D, education, institutions, and infrastructure, among others, as determinant factors for the development of eco-innovations.

In fact, the literature on eco-innovations considers that there are three main barriers to its development: financial, educational, and institutional barriers (Kemp *et al*., 2013).

On the one hand, the financial barrier implies that countries should have sufficient funds —internal or external R&D expenditures— for its development (De Marchi, 2012; Jo *et al.,* 2015). In this sense, meeting such conditions is easier in countries with higher income per capita. Therefore, the previous argument —resource scarcity— justifies that countries with a higher level of development show a higher volume of eco-innovations, while countries with a lower level of development show a lower volume of eco-innovations.

In addition, the role of education has also been pointed out. The introduction of eco-innovations requires particular skills of workers, which are more difficult to observe in countries with lower levels of development (Arranz *et al*., 2019). It means that a higher level of education will be aligned with a higher volume of eco-innovations.

Finally, the development of eco-innovation is also linked to the quality of the institutions. In this sense, some environmental regulations pull the development of eco-innovations. In addition, the level of economic development of the countries affects the implementation of environmental regulations (Andabaka *et al*., 2019). In this vein, the higher quality at the institutional level is associated with a higher volume of eco-innovations.

Therefore, this previous evidence justifies the analysis of the influence of the level of economic development on eco-innovation due to the fact that countries with lower levels of development usually have lower financial resources, education levels, and poorer institutional systems.

Furthermore, previous characteristics make the relationship between economic development and eco-innovations country-dependent (Costantini *et al*., 2023). In this sense, Hajdukiewicz and Pera (2023) postulated that there are differences between the groups of leading eco-innovators, catching-up eco-innovators, and EU average countries. Moreover, Jo *et al.* (2015) found also differences in the relationship between the level of development and eco-innovation for 49 countries in Asia and Europe.

Finally, it should be noted that most of the studies that analyse the level of economic development and eco-innovations have been focused on linear analysis, calling for some analysis considering non-linear approximations (Zhu *et al*., 2023).

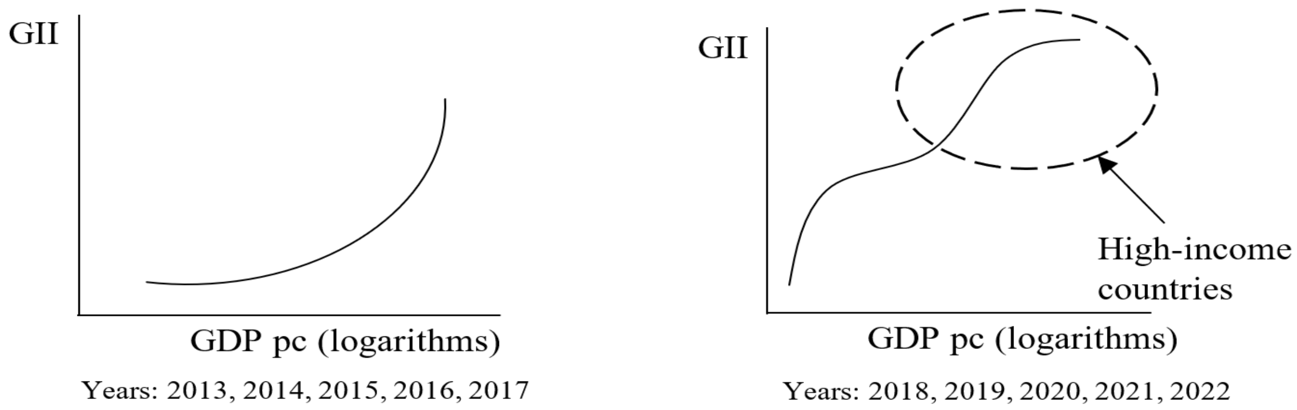
In this regard, previous efforts have been made in this direction considering traditional innovations (Dutta *et al*., 2022; Galindo Martín, 2008). In fact, the Global Innovation Index (GII)[3] reports include a graph analysing the shape of Economic Development and Innovation (Dutta, 2012). Focusing on these graphs between 2013 and 2022 (corresponding to the period analysed in this paper); it could be observed a positive relationship between economic development and innovation, although the shape of this link varies depending on the year analysed (see Figure 1). While from 2013 to 2017 the relationship has an exponential shape, in the remaining years the shape is cubic showing a logarithmic trend for countries with higher levels of GDP per capita.

To conclude, it is interesting to study the shape of the relationship between economic development and

[3] The GII variable is a proxy that allows the evaluation of the level of innovation in countries around the world.

FIGURE 1

THE SHAPE OF THE RELATIONSHIP BETWEEN GII AND GDP PER CAPITA



SOURCE: Own elaboration based on GII reports.

eco-innovations, considering their variation in the different years. This is particularly the focus of this study.

3. Data analysis

The main objective of this research is to observe the relationship between eco-innovation and economic development in the context of the European Union. To fulfil this goal, we use data from the EU-27 countries from 2013 to 2022. Specifically, we focus on two main variables.

On the one hand, the main explanatory variable is the GDP per capita, obtained from the World Bank (PPP, constant 2017 international USD).[4]

On the other hand, the variable referring to eco-innovation is the dependent variable and is measured through the Eco-innovation index. This indicator has been developed by the European Commission and it measures the environmental innovation performance of EU countries. It is the result of the analysis of different indicators grouped into five main dimensions: eco-innovation inputs, eco-innovation outputs, eco-innovation activities, resource efficiency outcomes, and socio-economic outcomes.[5] The data included in each of these dimensions to calculate the index are relevant indicators, published by public organisations such as Eurostat or the Organisation for Economic Cooperation and Development (OECD). The value of the eco-innovation index is calculated as an index number for each country and year, considering the EU value for 2013 as the base value.[6]

Descriptive statistics by country and year for these two variables can be found in Tables A2 and A3 in the Appendix. Table A2 shows that countries in the EU have

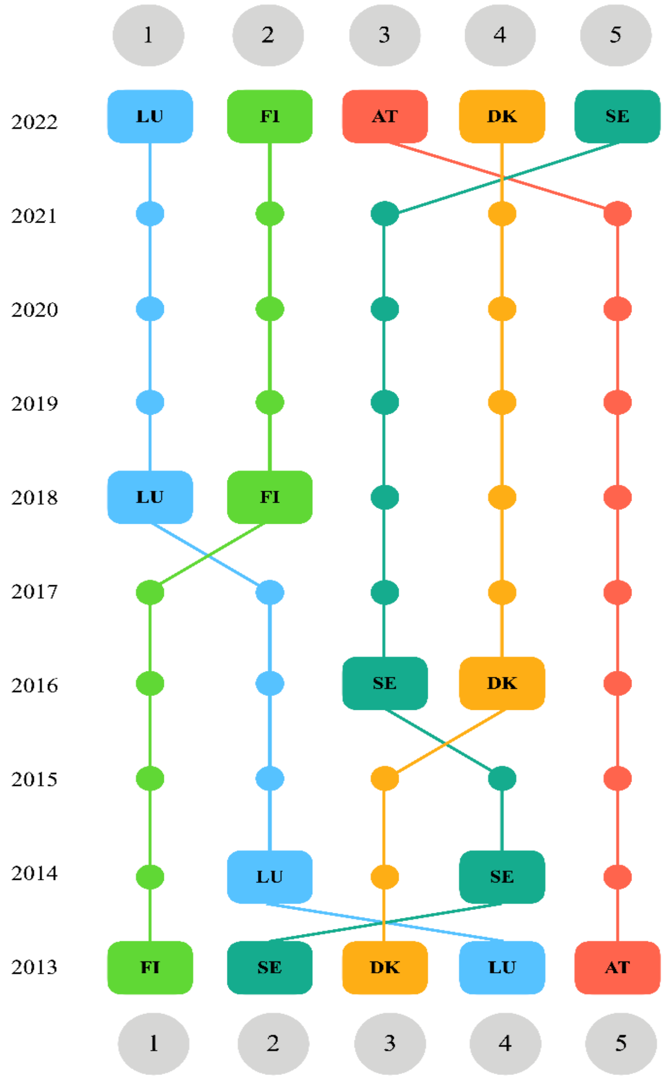
4 World Bank database – World Development Indicators (access October 2023). GDP is used in its logarithmic form to normalize the observed data and avoid the potential appearance of outliers in the sample, as *e.g.* Dutta (2012).

5 For more information about the eco-innovation indicator see the eco-innovation scoreboard https://green-business.ec.europa.eu/eco-innovation_en (access October 2023).

6 More information on the methodology of the index calculation is available at https://circabc.europa.eu/ui/group/96ccdecd-11b4-4a35-a046-30e01459ea9e/library/ddb0a147-f2fc-4555-849a-215c95ba592d/details (access December 2023).

FIGURE 2

TOP-5 ECO-INNOVATION LEADERS



NOTE: Country abbreviations are specified in Table A1 of the Appendix.
SOURCE: Own elaboration.

different levels of GDP per capita, and also it displays a positive trend in the period analysed. The same conclusion is obtained for the eco-innovation index (Table A3), showing an increasing tendency in the period analysed, and different levels depending on the country.

Regarding the eco-innovation levels, it is interesting to observe the values by country or, in other words, which are the top EU countries in terms of eco-innovation. Figure 2 shows the evolution of the top-5 countries in the period 2013-2022. The evolution of Finland and

TABLE 1

RANKING OF THE ECO-INNOVATION INDEX AND VALUES OF THE GDP PER CAPITA. YEAR 2022

Country	Eco-innovation index	GDP per capita
Bulgaria	57.73	26823.02
Poland	67.37	36798.19
Malta	79.76	48239.62
Hungary	81.15	35254.50
Romania	84.59	32738.19
Croatia	88.81	34025.45
Slovakia	94.41	33172.22
Cyprus	94.65	43620.12
Belgium	99.78	53155.91
Greece	101.59	31516.64
Lithuania	103.75	39592.80
Latvia	105.37	32733.47
Portugal	105.69	35746.39
Ireland	110.39	113870.78
Czechia	110.98	41666.51
Estonia	115.52	37826.01
Slovenia	115.86	42175.20
Spain	116.43	39834.08

Country	Eco-innovation index	GDP per capita
Netherlands	118.78	58584.62
Italy	129.39	43788.24
France	130.65	46019.66
Germany	141.18	53560.09
Sweden	160.95	54818.40
Denmark	167.49	59704.23
Austria	173.86	56280.51
Finland	178.01	49586.41
Luxembourg	179.02	115541.77

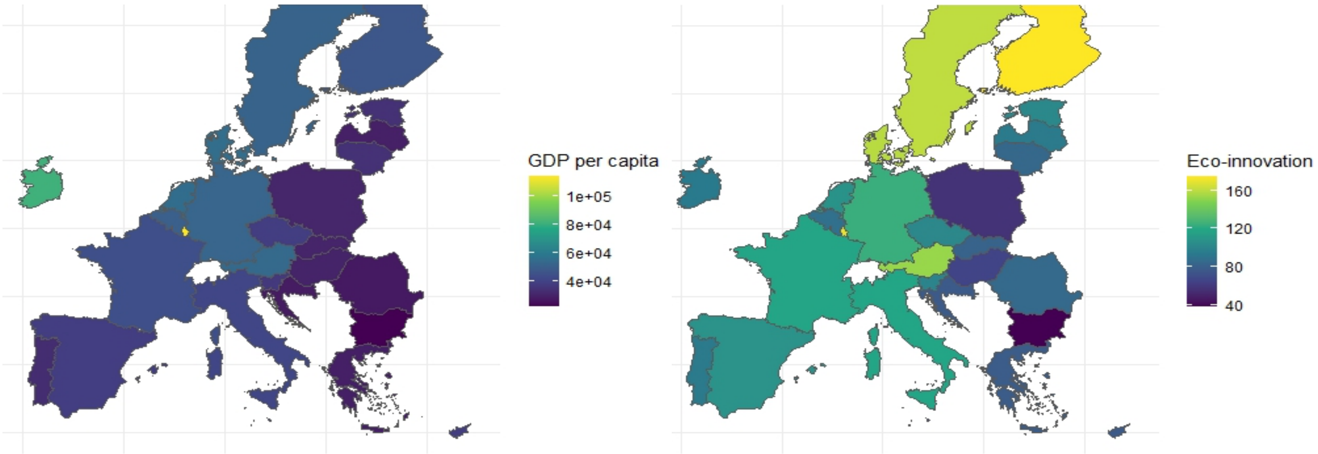
NOTES: (a) Eco-innovation scoreboard classification: Eco-innovation Catching-up (grey), Eco-innovation leaders (green) and Eco-innovation performer (yellow); (b) Values of the GDP per capita lower than the mean of the sample are coloured in red. The value of the average is equal to 48024,93 international USD (constant 2017, PPP); (c) We compare just 2022 because it is the last year available and due to the variation of the indicators during the years.
SOURCE: Own elaboration.

Luxembourg is particularly noteworthy, as they have been the two leading countries during the period. In the case of Finland, in 2013 it began as the leading eco-innovator, until 2018, when the two countries overtook each other. Luxembourg, for its part, began the period in fourth place, and from then on, its performance improved, becoming the leader of the ranking from 2018 onwards.

Based on the above, an in-depth descriptive analysis of the relationship between both variables could reveal

FIGURE 3

EU-27 COUNTRIES: GDP PER CAPITA AND ECO-INNOVATION INDEX. DATA AVERAGE BETWEEN 2013 AND 2022



SOURCE: Own elaboration.

some interesting results. To do that, we analyse comparatively our two variables although a ranking and using maps.

On the one hand, Table 1 shows the ranking of the Eco-innovation index according to the GDP per capita for 2022. We use for the comparison the last year available, *i.e.* 2022.

Table 1 shows three groups of countries, eco-innovation leaders (green), eco-innovation performers (yellow) and catching-up countries (grey).[7] This table displays that the average performers and the catching-up countries are the groups in which most countries have a GDP per capita lower than the mean of the whole sample, with some exceptions. The exceptions could be divided into two main groups: the first type of exception refers to those countries that, having a GDP per capita higher than the average, present lower values of the eco-innovation index. In this first group, we have Malta, Belgium and Ireland. The other group regards those countries that, having a GDP per capita lower than the average in 2022, present higher values of the eco-innovation index (Italy and France).

This could imply a positive relationship between the level of GDP per capita and the level of eco-innovation, although, due to the appearance of some countries that do not correspond to the particular group expected (the exceptions), we could advance that this relationship is country-dependent, it will depend on the year analysis and on the shape of the relationship.

On the other hand, the relationship could also be analysed from a specific country's perspective and on average, to overcome the possible year-dependent trends. Figure 3 shows the map of the EU-27 members. On the left side of the figure, the countries are coloured by the level of GDP per capita, while on the right side of the figure, the countries show the level of the eco-innovation index.

The first map (left side) shows that the level of GDP per capita in the countries is quite homogeneous,

[7] The eco-innovation scoreboard divides the EU countries into these three groups: the Eco-innovation leaders, average Eco-innovation performers, and the Eco-innovation catching-up.

TABLE 2

TYPE OF RELATIONSHIP DEPENDING ON THE POSSIBLE RESULTS OBTAINED FROM MODEL [1]

Type of relationship	$\widehat{\beta_1}$	$\widehat{\beta_2}$	$\widehat{\beta_3}$	
NO RELATIONSHIP	Zero or non-statistically significant different from zero	Zero or non-statistically significant different from zero	Zero or non-statistically significant different from zero	
MONOTONIC	+ sign	Zero or non-statistically significant different from zero	Zero or non-statistically significant different from zero	/
	– sign			\
CUADRATIC	+ sign	– sign	Zero or non-statistically significant different from zero	∩
	– sign	+ sign		∪
CUBIC	+ sign	– sign	+ sign	N
	– sign	+ sign	– sign	S

NOTE: /, \, ∩, ∪, N, S mean the possibilities of the shape of the curve in which the estimation can result, *i.e.* the form of the shape.
SOURCE: Own elaboration.

with Luxembourg and Ireland standing out as the economies with the highest GDP per capita.[8] This is not the case by level of eco-innovation (right side). Here, we can see that the distribution of countries is more heterogeneous. Despite these differences, we could predict a positive relationship between the two maps. Eastern European countries, which have the lowest GDP per capita values, also have the lowest Eco-innovation indexes; Southern European which have better GDP per capita and eco-innovation index values than Eastern European countries (they have lighter colours on both maps); and finally, with respect to Central and Northern European countries, both GDP per capita and the Eco-innovation index have the highest values.

Finally, we test the relationship between the variables using econometric techniques according to the following model —Equation [1]—, where *EI* refers to the Eco-innovation index, *G* is the GDP per capita, and *i* represents the country, *t* represents the year, α represents the unobserved individual effects, and ε is the error term.

$$EI_{it} = \beta_o + \beta_1 \cdot G_{it} + \beta_2 \cdot G_{it}^2 + \beta_3 \cdot G_{it}^3 + \alpha_i + \varepsilon_{it}, \quad [1]$$

This model allows us to test the complexity of the relationship by analysing the possibilities of the shape, including variable *G* in its logarithmic, quadratic, and cubic form.[9]

Table 2 shows the possibilities of the relationship based on the results obtained, following the works by Cansino *et al.* (2019) and Özokcu and Özdemir (2017).

8 Given that Luxembourg and Ireland are countries with high GDP per capita because of the existence of Multinational Enterprises we will replicate the analysis, without the consideration of these two countries.

9 Due to the differences in the GDP per capita within the EU, variable *G* will be used in logarithms.

TABLE 3

RESULTS OF THE ESTIMATION OF MODEL [1]. RANDOM EFFECTS

	Estimate	s.d.	p-value	
Intercept	39.142.507	12.440.556	0.001653	*
G	-11.112.411	3.479.831	0.001406	*
G^2	1.046.363	323.963	0.001238	*
G^3	-32.592	10.038	0.001167	*
R^2	0.4687			
Adjusted R^2	0.4627			
χ^2	234.655		<2.22e-16	*

NOTE: * means the parameter is statistically significant different from zero at 99 % confidence level; s.d. means standard deviation.
SOURCE: Own elaboration.

Based on Table 2 and paying attention to the results obtained after the estimation of model [1] [10] [11], shown in Table 3, an S-shape could be confirmed. The relationship between GDP per capita and the eco-innovation index is cubic as the corresponding estimated parameter, $\hat{\beta}_3$, is negative, $\hat{\beta}_2$ positive, and $\hat{\beta}_1$ negative. All the estimations are statistically significant individually, and the model, globally, is also significantly different from zero, which means that our model is well-determined as a whole. Additionally, we are explaining a relevant percentage of the variability of the data, with an adjusted R^2 of 46.27 %.

This relationship can be checked also by observing Figure 4. This figure graphically represents the data used for the analysis, together with the result for the estimation curve. On the left side of Figure 4, all the data used (countries and years) have been included, while on the right side, the average of the whole period for each country has been incorporated. Additionally, the value of the sample GDP per capita average has been included in each case. This value is useful because it provides the point from which it could observed as the shape of the curve changes.

The results in the previous Figure 4 (left side) show a positive relationship between eco-innovation and economic development in the first steps of the curve. In addition, it can be observed that the shape of the relationship changes as the GDP per capita of the countries increases.

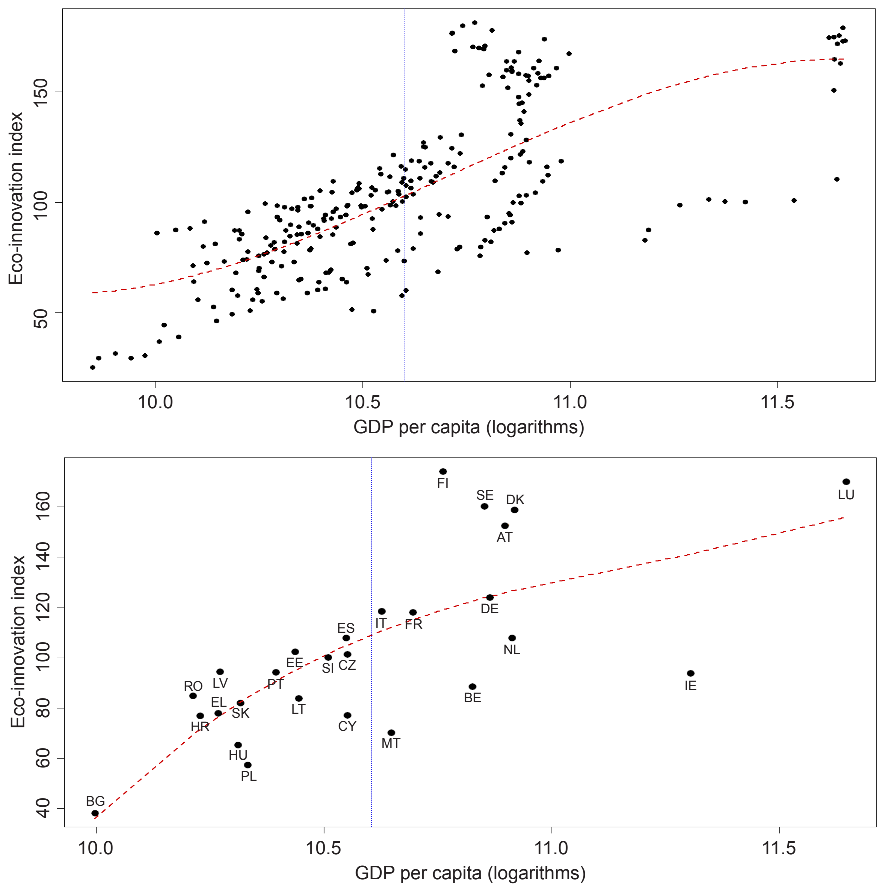
In addition, in Figure 4 (right side), paying attention to this splitting, we observe that among the 12 countries

10 The F Test for individual and/or time effects gives a p-value lower than 2.2e-16, which means the null hypothesis (pooling model) is rejected; the Lagrange FF Multiplier Test for panel models (Breusch-Pagan test) gives a p-value also lower than 2.2e-16, and again the null hypotheses (pooling model) is also rejected; finally, the Hausman Test for panel models gives a p-value equal to 0.6791, which means the null hypotheses (random effects) is not rejected, and the alternative one (fixed effects) is.

11 The reason for using panel methods is that they take advantage of the variability of the data by estimating and exploiting the information about the variability of the explanatory variables included in the model. If the variables do not have steep temporary variability, but they do have cross-variability, then the use of panel data provides extra capacity to estimate the model. Considering the corresponding tests, the random effects method is the one that best suits our data.

FIGURE 4

RELATIONSHIP BETWEEN *EI* AND *G*. COMPLETE DATASET AND DATA AVERAGE BETWEEN 2013 AND 2022 BY COUNTRY



NOTES: (a) Left side: the red dashed line represents the random effects estimation of model [1]; (b) Right side: the red dashed line represents the ordinary least squares estimation of model $EI_i = \alpha_0 + \alpha_1 \cdot G_i + \alpha_2 \cdot G_i^2 + \alpha_3 \cdot G_i^3 + u_i$; (c) The blue dashed line in both graphics represents the mean GDP per capita (logarithms) for the whole dataset. (d) Country abbreviations are specified in Table A1 of the Appendix.
SOURCE: Own elaboration.

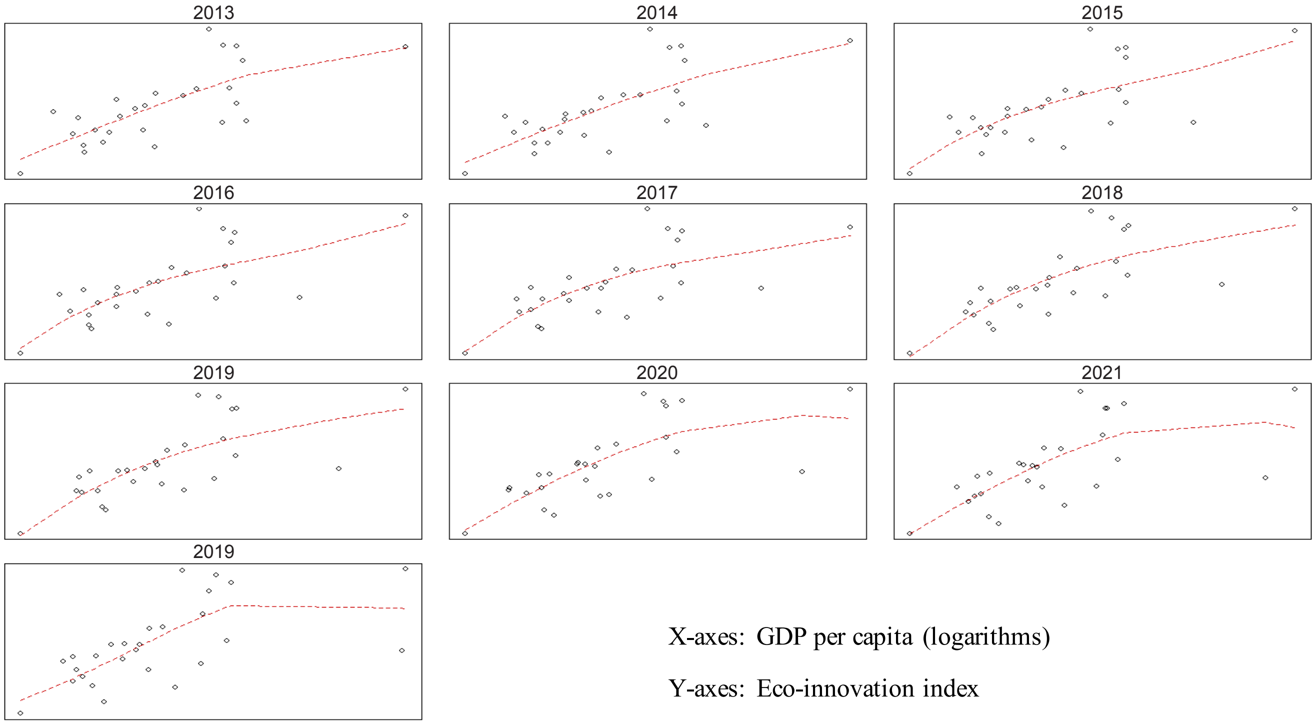
situated over the average income, 75% of them (9 countries) are considered leader countries regarding the 2022 eco-innovation raking presented in Table 1. The other three countries —Belgium, Ireland and Malta—, are the countries that we had identified as exceptions in the analysis of Table 1.

Finally, if we analyse the countries by GDP per capita (above and below the average), we can observe that the value of the average effectively divides the sample into two differentiated parts, demonstrating once again the changing shape of the relationship between economic development and eco-innovation (positive or exponential and, after that, logarithmic).

By year, the situation also supports the previous relationship. Figure 5 shows that the first years analysed have a (mostly) linear positive trend, while as the years

FIGURE 5

RELATIONSHIP BETWEEN *EI* AND *G*. BY YEAR



NOTE: The red dashed line for each year represents the ordinary least squares estimation of model: $EI_t = \delta_0 + \delta_1 \cdot G_t + \delta_2 \cdot G_t^2 + \delta_3 \cdot G_t^3 + \nu_t$
SOURCE: Own elaboration.

go by, the EU-27 countries start to draw a line that more closely resembles a logarithmic function. This means that when countries have lower income levels (corresponding to the early years), the line has a positive slope, while as countries grow (over the years), the trend starts to reach a point of stagnation and the curve becomes more like a logarithmic function.

Previous results of Figures 4 and 5 show that the relationship between eco-innovation and development could be interpreted as country-dependent and time-dependent. These figures show an exponential relationship between eco-innovation and development in the first part of the shape, *i.e.* with lower levels of GDP per capita, which is similar to that found by Andabaka *et al.* (2019), Pakulska (2021) and Urbaniec (2015). In addition, it can be observed that the shape of the relationship changes according to the increase in the GDP per capita of the countries, indicating that the shape (now logarithmic) of the link is time and country-dependent in line with Costantini *et al.* (2023) or Jo *et al.* (2015).

In this sense, our results indicate that for lower-income countries in the EU the curve tends to be linearly positive (or exponential), while for countries with higher GDP per capita, the curve acquires a logarithmic shape. This conclusion is coherent with the findings shown in Figure 1 for the GII. Several arguments will justify these results.

On the one hand, the first part of the curve (positive or exponential) is in consonance with classical growth models (Romer, 1990; Solow, 1956) which indicate that as economies grow, resources are freed up for investments in human capital, R&D or infrastructures that favour innovations and, thus, will also favour eco-innovations. It would be also in line with the eco-innovation literature, which considers that a higher level of GDP per capita affects positively the level of eco-innovation (Andabaka *et al*., 2019; Arranz *et al*., 2019; De Marchi, 2012; Jo *et al*., 2015; Kemp *et al*., 2013).

On the other hand, the logarithmic shape implies that at any level of eco-innovation (*i.e*., when countries are innovation-friendly and eco-innovation is a consolidated strategy), changes in economic development are not a relevant factor that affects the eco-innovation level. This implies that there will be other factors that will increase the eco-innovation levels, but not necessarily economic development. We could include in this group of factors: new technologies that facilitate the green transition or improvements in efficiency.

To sum up, a cubic relationship of an S-shape between the eco-innovation index and GDP per capita has been obtained in the period 2013-2022 for the EU-27 countries. These results are in line with what has been observed for general innovation (using the GII) in the world (Dutta *et al*., 2022).

4. Conclusions

Nowadays, eco-innovation and economic progress are intricately intertwined. The European Union (EU) understands that the integration of innovation into its environmental action programmes is essential for promoting sustainable development. In this sense, eco-innovation is viewed as a pivotal force driving the transition to a more environmentally friendly and economically sustainable society.

Given the relevance of this link, throughout this paper, the relationship between the level of economic development (measured by the GDP per capita), and the level of eco-innovation (measured by the eco-innovation index) in the European Union from 2013 to 2022 has been discussed.

This research analyses the relationship considering the EU countries included also in the 2030 Agenda, due to the limitation of data for the measurement of eco-innovation in other economies. However, similar results regarding the shape of the relationship could be expected in other countries not included in the group of high-income economies according to Dutta *et al*. (2022).

We contribute with this paper to the analysis of the shape of this relationship, our results finding a cubic relationship between both variables (S-shaped form). The S-shape implies that at a certain GDP per capita threshold, countries start to prioritise eco-innovation as an important factor in their economic development strategy. Once this shift takes place, significant investments in eco-innovation occur in the early stages, as evidenced by a consistently positive or exponential relationship between GDP per capita and eco-innovation levels. As countries reach a certain level of eco-innovation, usually associated with an increase in the GDP per capita, the positive and exponential relationship starts to diminish.

This evidence is in line with the findings of general innovation studies, which found that the relationship is country and time-dependent (Dutta *et al*., 2022; Çetin, 2013; Maradana *et al*., 2017; Sadraoui *et al*., 2014; Sinha, 2008). In addition, this finding adds evidence to the literature on eco-innovation for EU countries. The monotonic or exponential positive trend found in EU countries with GDPs per capita lower than the average is in connection with works such as Arranz *et al*. (2019), De Marchi (2012) or Jo *et al*. (2015), in which high-income levels are considered one of the reasons for justifying higher eco-innovation levels. However, the surprise here is the cubic curve described by the countries over the average in terms of GDP per capita, which demonstrates that the relationship is not always monotonically positive glimpsing a new stage in the process and therefore calling new policies for avoiding and overcoming the stagnation phase. In this sense, this logarithmic form shows that, in the case of the higher income countries, for any given level of eco-innovation, GDP per capita is not an influential factor of eco-innovation levels, and therefore, other factors, such as new technologies or efficiencies, would be the drivers for increasing its levels.

In summary, these observations emphasize the dynamic relationship between GDP per capita, eco-innovation, and countries' stages of development, shedding light on the evolution of eco-innovation in different economic contexts and showing several policy implications. Policies at the EU level that promote eco-innovations should vary according to the level of economic development of the countries (depending on which part of the S-curve they are in). Firstly, it is necessary to encourage substantial investments in eco-innovation during the initial stages of prioritizing it, leveraging the positive and exponential relationship between GDP per capita and eco-innovation levels. Secondly, policy packages are needed to ensure that countries with higher levels of economic development do not slumber in achieving more eco-innovations, as they are key to meeting the SDGs. In addition, it is also key to address technological constraints that could impede further progress in eco-innovation. This could involve supporting research and development efforts aimed at breaking down barriers to eco-innovation.

To conclude, this paper has some limitations. It is important to note that the cubic relationship found has been only studied in a unidirectional way. In addition, we only have introduced one explanatory variable (although in different forms), which may introduce omitted variables problems. In this sense, as possible lines of future research, the bidirectional relationship could be considered, as well as including more variables, such as education and institutions that could have relevance. In addition, this analysis could be applied to other samples of countries not included in the group of high-income economies. Finally, we propose as future research, the desegregation of the relationship analysed in the years 2020 and 2021, years involved in the coronavirus pandemic.

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APPENDIX - ADDITIONAL TABLES

TABLE A1

ABBREVIATIONS OF THE COUNTRY NAMES

Abbreviation	Country
AT	Austria
BE	Belgium
BG	Bulgaria
HR	Croatia
CY	Cyprus
CZ	Czechia
DK	Denmark
EE	Estonia
FI	Finland
FR	France
DE	Germany
EL	Greece
HU	Hungary
IE	Ireland
IT	Italy
LV	Latvia
LT	Lithuania
LU	Luxembourg
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SK	Slovakia
SI	Slovenia
ES	Spain
SE	Sweden

SOURCE: Own elaboration.

TABLE A2

STATISTICAL INFORMATION ON GDP PER CAPITA (LOGARITHMS)

	ln(GDP per capita)	Mean	Median	Maximum	Minimum	Standard deviation	Max - Min
By country	Austria	10.90	10.89	10.94	10.86	0.02	0.08
	Belgium	10.83	10.82	10.88	10.78	0.03	0.10
	Bulgaria	9.99	9.99	10.20	9.85	0.10	0.35
	Croatia	10.22	10.21	10.43	10.09	0.11	0.34
	Cyprus	10.55	10.57	10.68	10.41	0.09	0.27
	Czechia	10.55	10.56	10.64	10.42	0.07	0.21
	Denmark	10.92	10.92	11.00	10.85	0.04	0.15
	Estonia	10.43	10.45	10.56	10.29	0.09	0.27
	Finland	10.76	10.77	10.81	10.71	0.03	0.10
	France	10.70	10.70	10.74	10.65	0.03	0.09
	Germany	10.86	10.87	10.89	10.82	0.02	0.08
	Greece	10.27	10.26	10.36	10.21	0.04	0.15
	Hungary	10.31	10.32	10.47	10.14	0.10	0.33
	Ireland	11.28	11.30	11.64	10.90	0.22	0.75
	Italy	10.63	10.63	10.69	10.57	0.03	0.11
	Latvia	10.27	10.29	10.40	10.12	0.09	0.28
	Lithuania	10.44	10.45	10.59	10.26	0.11	0.33
	Luxembourg	11.65	11.65	11.66	11.62	0.01	0.04
	Malta	10.64	10.65	10.78	10.47	0.09	0.31
	Netherlands	10.91	10.91	10.98	10.85	0.04	0.13
	Poland	10.33	10.34	10.51	10.15	0.12	0.37
	Portugal	10.39	10.39	10.48	10.31	0.06	0.17
	Romania	10.20	10.23	10.40	10.00	0.13	0.39
	Slovakia	10.31	10.33	10.41	10.19	0.07	0.22
	Slovenia	10.51	10.51	10.65	10.38	0.08	0.27
	Spain	10.55	10.55	10.62	10.47	0.05	0.14
	Sweden	10.85	10.85	10.91	10.79	0.04	0.12

TABLE A2 (Continued)

STATISTICAL INFORMATION ON GDP PER CAPITA (LOGARITHMS)

	ln(GDP per capita)	Mean	Median	Maximum	Minimum	Standard deviation	Max - Min
By year	2013	10.50	10.54	10.88	9.85	0.33	1.03
	2014	10.50	10.56	10.88	9.86	0.32	1.01
	2015	10.53	10.59	10.88	9.90	0.31	0.97
	2016	10.55	10.60	10.90	9.94	0.30	0.96
	2017	10.59	10.64	10.92	9.97	0.29	0.95
	2018	10.61	10.66	10.94	10.01	0.28	0.93
	2019	10.64	10.69	10.95	10.05	0.27	0.89
	2020	10.59	10.62	10.92	10.02	0.27	0.90
	2021	10.65	10.68	10.97	10.10	0.25	0.87
	2022	10.69	10.71	11.00	10.20	0.23	0.80

SOURCE: Own elaboration.

TABLE A3

STATISTICAL INFORMATION OF THE ECO-INNOVATION INDEX

	Eco-innovation index	Mean	Median	Maximum	Minimum	Standard deviation	Max - Min
By country	Austria	152.43	151.01	173.86	137.27	9.63	36.59
	Belgium	88.57	89.29	99.78	75.91	6.53	23.87
	Bulgaria	38.04	34.30	57.73	25.18	10.75	32.55
	Croatia	76.84	74.83	88.81	64.16	7.11	24.65
	Cyprus	77.16	73.66	94.65	65.39	10.07	29.26
	Czechia	101.58	101.81	110.98	92.61	5.86	18.37
	Denmark	158.95	158.36	167.49	151.84	4.20	15.65
	Estonia	102.43	98.72	115.52	89.93	7.59	25.59
	Finland	174.23	173.75	181.55	168.67	4.59	12.88
	France	118.07	116.91	130.65	109.07	6.95	21.58
	Germany	124.06	122.51	141.18	109.83	9.48	31.35
	Greece	77.84	74.86	101.59	55.94	14.15	45.65
	Hungary	65.31	64.38	81.15	52.64	8.30	28.51
	Ireland	93.82	99.58	110.39	77.28	10.77	33.11
	Italy	118.55	118.84	129.39	102.55	7.76	26.84
	Latvia	94.40	97.45	105.37	80.06	8.16	25.31
	Lithuania	83.89	83.61	103.75	66.24	11.53	37.51
	Luxembourg	170.10	173.19	179.02	150.74	7.94	28.28
	Malta	69.99	73.67	93.54	50.77	13.66	42.77
	Netherlands	108.06	107.00	118.78	95.10	7.74	23.68
	Poland	57.04	57.80	67.37	46.45	6.29	20.92
	Portugal	94.38	95.01	105.69	82.18	7.47	23.51
	Romania	84.89	85.38	91.36	77.61	3.91	13.75
	Slovakia	82.15	83.76	94.41	68.13	7.26	26.28
	Slovenia	100.11	97.66	115.86	89.74	8.08	26.12
	Spain	107.81	106.43	116.43	104.47	3.72	11.96
	Sweden	160.35	160.45	168.19	152.99	4.09	15.20

TABLE A3 (Continued)

STATISTICAL INFORMATION OF THE ECO-INNOVATION INDEX

	Eco-innovation index	Mean	Median	Maximum	Minimum	Standard deviation	Max - Min
By year	2013	99.21	95.60	168.67	25.18	41.72	143.49
	2014	102.48	91.70	176.61	29.42	43.18	147.19
	2015	104.11	97.22	176.70	31.65	43.00	145.05
	2016	105.61	100.78	180.02	29.52	42.55	150.50
	2017	108.12	104.18	181.55	30.60	43.05	150.95
	2018	107.16	99.59	169.91	36.94	40.00	132.97
	2019	110.32	101.15	169.41	39.13	38.96	130.28
	2020	113.03	105.83	170.55	44.41	39.41	126.14
	2021	116.48	110.76	170.89	55.85	35.15	115.04
	2022	121.75	113.25	178.01	57.73	38.22	120.28

SOURCE: Own elaboration.