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Dynamics of environmental technological capacity: An analysis between developed and developing countries (1990-2015)

Dinâmica da capacidade tecnológica ambiental: uma análise entre países desenvolvidos e em desenvolvimento (1990-2015)

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ABSTRACT: The literature on national innovation systems highlights that investments in environmental innovation are influenced by the magnitude of the multidimensional characteristics of each economy. In order to build the possible bases for environmental technological development, countries need to advance in several issues related to scientific, technological, educational and health infrastructure. Thus, the article aims at investigating the evolution of different characterizations (developed and developing countries), in the period between 1990 and 2015. For that purpose, the methodology applied was Principal Component Analysis (PCA) and regression model with panel data. The results revealed that scientific characteristics and gas emissions were determining factors for the countries' innovative environmental performance over the years, especially developed ones. Furthermore, efforts were made by developing countries such as Brazil, China and India, in favor of a new environmental technological paradigm.

Keywords: environmental innovation; developed countries; developing countries; principal component analysis; panel data analysis.

RESUMO: A literatura sobre sistemas nacionais de inovação (SNIs) destaca que os investimentos em inovação ambiental são influenciados pela magnitude das características multidimensionais de cada nação. Para construírem as bases possíveis ao desenvolvimento tecnológico ambiental, os países precisam avançar em várias questões referentes à infraestrutura científica, tecnológica, educacional e sanitária. Nesse contexto, o presente artigo teve como objetivo investigar a evolução de diferentes características de 40 países (desenvolvidos e em desenvolvimento), no período de 1990 a 2015, considerando um conjunto de variáveis extraído dos bancos de dados da OCDE e do Banco Mundial. Para tanto, a metodologia aplicada baseou-se em Análise de Componentes Principais (ACP) e em um modelo de regressão com dados em painel. Os resultados revelaram que as características científicas e as emissões de gases foram fatores determinantes para o desempenho inovativo ambiental dos países, especialmente os países desenvolvidos, ao longo dos anos. Ademais, observou-se esforços dos países em desenvolvimento, como por exemplo, Brasil, China e Índia, em prol de um novo paradigma tecnológico ambiental.

Palavras-chave: inovação ambiental; países desenvolvidos; países em desenvolvimento; análise de componentes principais; análise de dados em painel.

1. Introduction

Concerns about the environmental damage caused by significant economic growth over time have increased since the second half of the 20th century. Specifically, in 1987, with publication of the World Commission on Environment and Development (WCED) report, the starting point for the sustainable development issue was observed. As a result, the environment and technology issue, especially in advanced countries, has become an agenda for different sectors and agents in the innovation field, such as governments, corporations, universities, research centers and social movements.

Thus, since the 1980s, the countries belonging to the Organization for Economic Cooperation and Development (OECD) have been changing the support pattern for industry, incorporating measures that integrate international trade policies with the industrial and technological agenda. Instead of subsidizing companies through specific and detailed research and development contracts, the governments of these countries began to create conditions for productive activity to be organized in a systemic and integrative way. In Brazil, from the mid-1990s onwards, there was growing investment in innovation policies, such as sectoral funds to finance research and formulation of the Innovation Law. However, the theme of innovation has remained closely linked to economic concerns such as competitiveness, demand pressures and investments (Andrade, 2004).

Particularly in the 1990s, the competitiveness and innovation logic incorporated a more specific debate about a possible trade-off between environmental regulation and competitiveness, reinforcing the thesis of a necessary compromise between economic growth and sustainability. On the other hand, Porter's hypothesis also prevailed, in which the imposition of adequate environmental standards can encourage companies to adopt innovations that reduce the total costs of a product or increase its value, improving competitiveness of the companies and, consequently, of the country (Koeller *et al*., 2019).

In this context, the concept of Environmental Innovation (EI) emerges as a solution to the adverse effects of economic growth and encompasses different dimensions such as environmental, social and institutional (Rennings, 2000; Koeller *et al*., 2019). Environmental innovation also demands the integration of skills along the company's production chain, in which environmental regulation encourages the use of new materials and technologies, different functionalities and uses, as well as alternative disposal methods for products (Kesidou & Demirel, 2012; Pinsky *et al*., 2015). Thus, environmental innovation also includes pollution control innovation (new, better or more economical technologies), green products, clean production technologies, sustainable energy and transport technologies, waste reduction and management techniques. For Kemp & Pearson (2007), the basis of the EI concept is centered on environmental performance to the detriment of a company's environmental goals, for example, as what matters are not corporate objectives and intentions, but the positive environmental results brought about by EI.

The OECD points out that environmental innovation reflects a reduction of the environmental impact and not only a limitation in innovating products, processes and organizational methods, but also includes innovation in social and institutional structures, in addition to increasing competitiveness of the companies and countries that "eco-innovate" (Kesidou & Demirel, 2012). It is worth mentioning that competition promotes innovation, and greater innovation helps ensure greater competitiveness. Thus, environmental innovation can also be defined as any action taken to increase effectiveness of a given system, as well as to enhance its energy efficiency, reducing externalities and production time (Raynolds *et al*., 2002).

However, criticism directed at environmental technologies assumes that they do not require new technological or scientific paradigms. However, scientific advances highlight the technological directions of countries that converge with the global environmental debate, such as energy consumption and preservation of natural resources. Thus, the main criticisms refer to countries that rely on the context of producing more incremental innovations, configured by technologies called "end of the line" (end-of-pipe), and that do not leverage specific and more radical innovations, configured by clean technologies (Freeman, 1996).

Therefore, environmental innovation also requires a broad infrastructure that includes different dimensions, such as cultural, institutional and organizational. The key issue of environmental innovation integrates elements like technology, markets and society that contribute to innovations bringing about alternatives to environmental issues, including cleaner production (reduction of the environmental impact in the life cycle), more efficient processes (waste reduction), alternative technologies (reduction of emissions), new services (product consumption replacement or reduction) and innovation in systems (measuring and monitoring) (Pinsky *et al.,* 2015).

In summary, the main objective of the article was to identify countries that, even with different characteristics among them, had a similar pattern of behavior according to the components specified. In other words, developed countries such as Japan and the United States, and developing countries such as China and India, obtained similarities in their configurations when their characteristics in relation to environmental technologies and their scientific dimensions were equated. In addition, the hypothesis was confirmed that countries more prone to the production of environmental technology would be those that are more consolidated in terms of scientific infrastructure and also more polluting.

Thus, the current paper investigated the multidisciplinary configurations of developed and developing countries, focusing on a set of variables at two different points in time: 1990 and 2015. After the first static analysis, based on the use of the Principal Components Analysis (PCA) multivariate technique, the time dynamics were investigated and the importance of the different scientific and environmental dimensions was verified, under the countries' environmental technological development process and considering the period from 1990 to 2015. For the second stage, the panel data methodology was applied with the objective of specifying the systemic dynamics of the set of countries that favored innovative environmental activities, considering, in this stage, five-year intervals contained throughout the period between 1990 and 2015.

In addition to the Introduction, this paper is organized into another five items. In Section 2, changes in the global technological paradigm are presented. The following item identifies the perspectives and differences between developed and developing countries in terms of environmental innovations. In the fourth section, the database and the applied methodology are detailed, namely Principal Component Analysis and Panel Data. Finally, in sections 5 and 6, the results and final considerations of the paper are woven, highlighting the contributions and main results under the effect of the technological, scientific and socioeconomic dimensions, according to the sample of countries.

2. Changes in the global technological paradigm

The development of environmental technologies involves complexity and is outlined by a continuous process of improvements. This process ranges from improving and conserving raw materials and energy to reducing the use of toxic substances and waste and polluting gas emissions, throughout the entire production cycle (Corrocher *et al*., 2021). According to Hall & Vrendenburg (2003), the process is complex due to the generation of environmental innovations that contradict the perspective of economic rationality, in which it is postulated that business actions should exclusively aim at increasing profit (Jabbour, 2010).

In order to understand the shift from the technological paradigm towards one in the environmental context, it is necessary to analyze the historical context. In the late 1970s, a set of studies began to emerge that, in a more systematic way, sought to examine the role of technological change in the industrial and economic development of countries and companies. The new approach, also known as neo-Schumpeterian or evolutionary, has the profile of advocating the replacement of current production methods and unsustainable consumption patterns and the emergence of the development and rapid diffusion of technologies that are more suitable for the environment (Freeman & Soete, 2008). In addition, research confirms an environmentally sustainable route to solving unemployment and problems related to food supply and demand (Kivimaa & Mickwitz, 2006).

It is worth mentioning that the increase in global competitiveness, the growing demand for operational efficiency with cost and quality reduction, socio-environmental regulations, pressure from interested parties (stakeholders) and rapid technological transformation challenge companies to innovate with a focus on sustainability (Pinsky *et al*., 2015). On the other hand, the same competitiveness provided a significant financial boost obtained from neoliberal trends, which caused governments to retreat, collaborating in the revolution of Information and Communication Technologies (ICTs). More specifically, computers, the Internet and Japanese production methods provided a new paradigm that allowed for the rejuvenation of mature technologies, both through reorganization and optimization of resources and inputs (Kivimaa & Mickwitz, 2006).

In this way, the current techno-economic paradigm, based on the potential of ICTs, has modified the economic space and the forms of competition. As the forms of competition and the conditions for success in each type of market are different, countless possibilities are opened for new entrants and for innovative producers from developing countries, for example, from natural resources, through manufacturing and to the service sector (Kemp & Pontoglio, 2011). Although investments in research and development (R&D) are substantially increasing in sectors such as infrastructure, energy and agroecology, sustainability is not (yet) the main factor that motivates them to change the paradigm (Su & Moaniba, 2017). In the transport infrastructure area, for example, congestion and safety are higher on the agenda than the sustainability factor.

Therefore, the literature on innovation has shown that gradual investments in environmental technologies are strongly influenced by the companies' competitive capabilities. Companies that build organizational capabilities and practices, such as reducing the use of raw materials and inputs, recycling, pollution prevention and less polluting design of green products, have greater chances of investing in environmental innovation (Popp, 2011; Kesidou & Demirel, 2012).

It is noteworthy that the use of science and technology policies to achieve environmental goals constitutes a new focus for technology policies (Freeman & Soete, 2008). The need to integrate environmental policies into other aspects of technology policies is also recognized by several countries (Vona & Patriarca, 2011). Once environmental policies and technology policies are integrated and affect the development of environmental technological innovations, several positive synergies arise within the technological development of nations. However, political priorities are still one of the main obstacles to the convergence of agendas, especially in developing countries (Gonçalves Montenegro *et al.*, 2021). Finally, countries that aim at a paradigm shift with a profile linked to environmental issues must seek, in the first place, to reconcile issues that involve a sustainability agenda compatible with its use in the long term, in addition to continuous growth and development of their technological profile (Kivimaa & Mickwitz, 2006).

3. Differences between the environmental technological capabilities of developed and developing countries

Between the 1970s and 1980s there was growing public awareness and concern about environmental damage, causing a substantial amount of innovation to occur at a global level; in some cases because of specific accidents, such as in Japan. In the United States, Japan and Germany, the share of environmental patents was higher than the corresponding share of pollution abatement spending in GDPs. Furthermore, the Japanese environmental innovation rates were consistently high. With this, certain plausible connections between environmental regulation and innovation begin to emerge. In these three countries, over time, innovation responded to spending on reducing pollution, an indicator of the severity of environmental regulations. Furthermore, environmental patent rates in developing countries were also high, reaching 2% in many years in Brazil. However, domestic innovation was merely a path to new technologies. ‘Imports’ of environmental technologies (foreign patents registered in developing countries) were substantial. Developing countries, especially in East Asia, have often chosen to obtain technologies based on anti-pollution equipment, that is, innovation in reducing end-of-pipe pollution (Lanjouw & Mody, 1996).

Furthermore, countries that have ‘utilitarian’ patent systems such as Korea and Mexico show significant patent activity in the environmental fields. Foreign inventors usually registered their ‘important’ and widely applicable patents in developing countries. Foreign patents also protect intellectual property embodied in pollution control equipment exported to developing countries (Lanjouw & Mody, 1996). It is evident that there is an ongoing “green” manufacturing process in industry, in particular, a “green” energy systems process. Carbon Capture and Sequestration (CCS) technologies play an important role in reducing the carbon dioxide (CO_2) emission gap. Countries such as Canada, UK, USA, Kazakhstan, Austria and France can be identified as producing leading technologies within a green technology portfolio. In other words, from the aforementioned portfolio it is possible to identify the countries' pattern of green technological accumulation for climate mitigation, in addition to indicating a concern with air pollution control (Gomes & Corazza, 2013).

It is possible to observe, for example, data on investments and creation of new capacities, increasingly directed towards green and renewable energy options. What is striking about the current surge in additions to renewable energy is that China has emerged the strongest player as by far, now accounting for the largest share of investment, particularly in wind power, solar PV and smart grid technology. The emergence of China as a leader is yet another indication of the fundamental change in the techno-economic characteristics of global energy systems (Mathews, 2013).

Great innovations, such as solar energy generation in deserts using Concentrated Solar Technology, promise as many associated investment opportunities as entrepreneurs to find them. According to Porter (1991), a country's prosperity is created – not inherited from natural resources – and therefore depends on its industry's ability to innovate and update. Innovation comes from individual companies, but it is also fostered by judicious governmental regulations that reflect country specificities. Porter & Van der Linde (1995) demonstrated that properly designed environmental standards can trigger innovations that may partially or more than fully offset the compliance costs.

Key initiatives whose costs have been significantly overstated include the Montreal Protocol, adopted to phase out ozone-depleting compounds, as well as the US Acid Rain Program aimed at reducing sulfur dioxide (SO_2) emissions from fossil fuel burning plants. Case studies and retrospective analyses conducted for a variety of regulations show that, in all cases, reducing emissions at source is much more economical than is generally expected. However, cleaning beyond the source is often much more expensive than anticipated.

While there is a large body of evidence that regulatory environmental initiatives can improve competitiveness, it is obvious that this depends, at least to some extent, on the design of the initiatives in question (Raynolds *et al*., 2002). With regard to the environmental fields identified in the patent data, it is the machine suppliers and not the technology users that have been the main innovation source. Local governments have been particularly assiduous in enforcing pollution standards. According to Raynolds *et al*. (2002), the United States was in an intermediate position, and Germany and other European countries were, on average, at the lower end. However, Germany made tremendous strides over the period, not only instituting high standards, but promoting innovative institutional development in areas such as recycling and eco-labelling. From 1972 to 1976, total expenditures in the United States increased from $15 billion to nearly $20 billion. Spending in Japan on pollution control increased from $14 billion in 1976 to a peak of $19 billion in 1981, immediately after the peak in spending in the United States (Lanjouw & Mody, 1996).

While policy strategies can exert direct effects by producing some results, they are mainly implemented by modifying existing policy instruments or creating new ones. In the particular case of the Finnish technology policy, the subset of policy instruments evaluated are R&D programs in technology. Political pressures coming from outside the system (general population, environmental organizations) can sometimes directly affect the formation and focus of technology (Kivimaa & Mickwitz, 2006). Demand factors require corporate responsibility, and the waste management literature suggests that they will affect a company's decision to invest in eco-innovation (Kesidou & Demirel, 2012).

In a broad sense, the efforts of countries and groups of companies in favor of environmental technological development cannot be ignored. In this item, both from the point of view of supply and consumer behavior, it was observed that changes are relevant to countries' economic growth and technological path. The next item will present the tools and variables that will make it possible to investigate in greater depth the differentials and asymmetries across countries.

4. Methodology and database

4.1. Principal Component Analysis

A longitudinal dataset is one that follows a given sample of individuals over time and therefore provides multiple observations about each individual in the sample. The term "panel data" refers to grouping observations into a cross-section of households, countries and firms over various periods of time. More importantly, longitudinal data allow a researcher to analyze a number of important economic questions that cannot be addressed using cross-sectional or time-series datasets.

Using panel data also provides a means of solving or reducing the magnitude of a key econometric problem that often arises in empirical studies, i.e., the frequently heard claim that the real reason why one finds (or does not find) certain effects is the presence of omitted variables (poorly evaluated or not observed) that are correlated to explanatory variables. By resorting to information about the intertemporal dynamics and the individuality of the entities under investigation, it is possible to better control, in a more natural way, the effects of absent or unobserved variables.

The panel data methodology involves two dimensions, namely: cross-section and time-series. Calculating panel data estimators is expected to be more complicated than analyzing cross-section or time-series data. However, in certain cases, panel data availability can actually simplify calculation and inference (Alonso-Borrego & Arellano, 1999). With additional and more informative data, it is possible to produce more reliable parameter estimates. Furthermore, panel data are better able to study the dynamics of fit. Cross-sectional distributions that appear relatively stable hide a myriad of changes. According to Hsiao (2014), the advantages of this method in relation to cross-sectional data and time series are as follows:

(a) greater ability to construct more realistic behavioral hypotheses;

(b) it allows the observation of dynamic relationships between individuals;

(c) it makes it possible to control the impact of omitted variables;

(d) it generates more accurate predictions for individual outcomes;

(e) it simplifies computational implementation and statistical inference.

Regarding the individual effects, they are correlated with the explanatory variables of the model and, therefore, the ordinary least squares estimator becomes inconsistent because there may be factors that determine the dependent variable, but which are not being considered. In these cases, it is customary to use the fixed effects estimator because it remains consistent and feasible. Two extensions of the regression model for pooled data arise, namely: the fixed effects model and the random effects model. According to Cameron & Trivedi (2005), fixed effects models present the condition that the independent variables are correlated to the effects of the individual level and, therefore, a consistent estimation of the model parameters requires elimination or control of the fixed effects. On the other hand, in the random effects model it is assumed that the individual effect is purely random and is not correlated to the explanatory variables.

A major limitation of the internal estimate refers to the fact that the coefficients of the independent time-invariant variables are not identified in the inside model. In the case of the current paper, the short panel measures the association between individual-period changes in the regressors (Levin, Lin & Chu, 2002) and individual-period changes in the dependent variable (Baltagi, 2005). In this case, the first difference estimator will be the Ordinary Least Squares (OLS) estimator. Data characteristics, in particular panel size, influence the choice of an ideal estimator for panel data models (Wooldridge, 2010).

Thus, the empirical model proposed in this article is represented by:

$$Y = \beta_0 + \beta_1 EM + \beta_2 PC + \varepsilon \tag{1}$$

Where Y represents the dependent variable (development of environmental technologies), $\beta_1 EM$ and $\beta_2 PC$ are the explanatory variables (gas emissions and scientific output, respectively) and ε represents the error term with its usual properties.

In short, the panel data methodology will be applied to the empirical model in order to estimate the relationships proposed in the theoretical and empirical framework of sections 2 and 3. In general, the theoretical model to be estimated can be presented as follows:

$$Y_t = a + X_t\beta_t + \delta_t + \gamma_t + u_t \quad (2)$$

Where Y_t is the dependent variable, X_t is a k– vector of the explanatory variables and u_t are the error terms for i=1,2,3...M units of cross-sections (countries) and for the period t=1,2,..T (years). Parameter a represents the general constant of the model, while δ_t and γ_t characterize the specific effects of cross-section units and periods (random and fixed effects), respectively.

Therefore, data characteristics, in particular sample size, influence the choice of an ideal estimator for panel data models (Baltagi, 2005). For a panel with a long-term dimension, the computationally simple Anderson-Hsiao estimator performs well (Hsiao, 2014). To control problems related to endogeneity and given the possibility that the independent variables are correlated, we opted for estimation using the instrumental variables method by 2-stage least squares with error component (EC2SLS). The role of the two-stage least squares estimator (MQ2E) is to replace the endogenous explanatory variable by a linear combination of the model's predetermined variables. Thus, using it in place of the original endogenous variable promotes the combination as an explanatory variable.

According to Wooldridge (2010), when cross-sectional analysis is used (time series and panel data) and the MQ2E is properly applied, the results obtained by this method can provide a more efficient estimate in the presence of endogenous explanatory variables than those obtained by means of OLS. However, using MQ2E can present problems regarding the instrumental variables being considered weak, that is, when the instrumental variables are correlated to the error term or have a small correlation to the endogenous explanatory variables. Thus, the Sargan test was performed, which indicated validity of the instruments, as will be explained in the Results section.

4.3. Database

Before the description of the variables used in both methodologies explained in the previous section, the descriptive statistics (Table 1) of all the variables were calculated, as well as the correlation matrix (Table 2). The results are presented below.

The correlation matrix (Table 2) helped to verify if there was any case of autocorrelation between the variables used in the Principal Components Analysis (PCA), which was confirmed between some variables and does not invalidate use of the instruments. In this article, the OECD database was used according to the scope of countries and technologies related to the environment. In all, 40 countries (developed and developing) were approached in the survey, considering the period between 1990 and 2015. The countries selected for the sample were the following: Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Czech Republic, China, Cuba, Denmark, Germany, Finland, France, Greece, Holland, India, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Malaysia, Mexico, Moldova, Norway, Poland, Portugal, Romania, Russia, Singapore, Spain, South Africa, Sweden, Switzerland, Turkey, United States, United Kingdom and Ukraine. It is important to point out that both methodologies evaluate the period differently. That is, PCA specifically compares two years (1990 and 2015) and panel analysis uses all five-year intervals contained

TABLE 1 – Descriptive statistics of the variables. ET = Environmental Technology; SP = Scientific Production; EM = Emissions of polluting gases; EX = Life expectancy at birth; SA = Sanitation; PD = Population density; DW = Drinking water; GP = GDP per capita.

Variables	Mean	Standard Deviation	Minimum	Maximum
ET	2.4542	5.9659	0	31.5
SP	3.4496	6.6687	6.5	42.3654
EM	8.1229	4.5573	0.000001	26.2
EX	75.6496	5.4103	53.4	83.8
SA	91.4717	14.42239	16.4	100
PD	287.7262	968.9199	2.2	7,806.8
DW	97.2992	4.8045	79	100
GP	2.9117	3.6372	-11.5	24

SOURCE: The authors.

TABLE 2 – Correlation Matrix corresponding to the variables. ET = Environmental Technology; SP = Scientific Production; EM = Emissions of polluting gases; EX = Life expectancy at birth; SA = Sanitation; PD = Population density; DW = Drinking water; GP = GDP per capita.

Variables	ET	SP	EM	EX	SA	PD	DW	GP
ET	1							
SP	0.6877	1						
EM	0.3011	0.2945	1					
EX	0.2290	0.1360	0.3327	1				
SA	0.1982	0.0509	0.4724	0.7556	1			
PD	-0.0293	-0.0581	0.1001	0.1317	0.0913	1		
DW	0.1371	-0.0028	0.4532	0.7052	0.6766	0.0906	1	
GP	-0.0276	0.0265	-0.0440	-0.0325	-0.1008	0.1496	-0.0891	1

SOURCE: The authors.

in this period (i.e., 1990, 1995, 2000, 2005, 2010 and 2015) for the analysis.

To carry out the estimates, variables based on different dimensions were used, such as those related to technological, scientific and socioeconomic infrastructure, explained below:

i) Environmental Technology (ET): The variable represents a proxy for the environmental technological activity of the sample countries, according to the years surveyed. It can be defined as a strategy for developing technologies related to the environment, which was constituted by the percentage (%) of inventions of environmental technologies, whose data were extracted from the OECD. The indicator aims at configuring the effort of environmental technological development and its role as a promoter of environmental innovations (Rave *et al*., 2011; Dechezleprêtre *et al*., 2011).

ii) Scientific Production (SP): The scientific production indicator is represented by the percentage (%) of scientific and technical articles from the countries, which were extracted from the World Bank database. The purpose of using this variable is to investigate the relationship and effects of scientific activity for the environmental technological development capacity, for the countries analyzed in the sample (Lanjow & Mody, 1996).

iii) Emissions of polluting gases (EM): The indicator that made it possible to verify the degree and magnitude of damage caused by economic activities to health and the environment was represented by carbon dioxide (CO_2) emissions, measured in metric tons of carbon per capita. The information source was the World Bank database. Use of the variable is justified because it is associated with the climate change problem and because of the characterization of the most polluting countries in terms of their different dimensions associated with the consequences of greenhouse gases (Brunnermeier & Cohen, 2003).

The socioeconomic indicators were represented by the following variables collected from the World Bank database:

iv) Life expectancy at birth (EX): Characterized by the average years of life of the population of the countries.

v) Sanitation (SA): Represented by the percentage of the population with disabilities in access to basic sanitation services.

vi) Drinking water (DW): Configured by the percentage of people who have restrictions on access to basic drinking water services in the sample countries.

vii) Population density (PD): The indicator was constructed by dividing the number of inhabitants of each country by its respective area (km^2).

The four variables mentioned above had the objective of relating the development of environmental technologies to the well-being and quality of life of the countries' population. Specifically, the idea of using a socioeconomic dimension is centered on the understanding that countries are willing to change their environmental technological paradigm and, at the same time, comply with a minimum level of socioeconomic infrastructure.

Finally, the following was also considered as a variable:

viii) GDP *per capita* (GP): The indicator represents the annual percentage growth of the *per capita* Gross Domestic Product (GDP) of the selected countries and was also extracted from the World Bank database. The purpose of using this variable was to associate the countries' economic development degree with the capacity for environmental technological development. As the sample of countries is comprised by nations with different economic development levels, the analysis through the variable allowed identifying which countries would be more associated with this proposal.

5. *Results*

As a way of characterizing and comparing the static dynamics (comparing the years 1990 and 2015) for all 40 countries in the sample and through the eight variables originally chosen (original random vector), the results of the Principal Components Analysis (PCA) for the two respective years were chosen. The first stage consisted in carrying out the KMO adequacy test, in which both for 1990 and for 2015 its result was above 0.50 (0.72 and 0.71, respectively). This indicates that the variables are properly fitted to the data and testing the overall data consistency. Bartlett's sphericity test values with significance levels ($p<0.05$) indicate that the matrix is favorable, rejecting the null hypothesis that the data matrix is similar to an identity matrix. In general, the results of the KMO and Bartlett's sphericity tests tend to be uniform, accepting or denying the possibility of factoring the data matrix. Likewise, this result indicates that high values (between 0.5 and 1.0) represent that the analysis is appropriate, whereas values below 0.5 indicate that the analysis may be inadequate. The Bartlett and KMO tests are used in factor analysis, with the article analysis method (PCA) being a member of this factor analysis category (Hair Jr. *et al*., 2009, p. 33). Table 3 brings together the results obtained from the PCA based on individual and accumulated percentage variances.

TABLE 3 – Variance of the components (1990).

Components	Variance	
	Individual	Accrued
Comp1	41%	41%
Comp2	20%	61%
Comp3	15%	76%
Comp4	10%	86%
Comp5	7%	93%
Comp6	3%	96%
Comp7	3%	99%
Comp8	1%	100%

SOURCE: The authors.

Based on the results in Table 3, the first component was represented by 41% of the total data variability. The second component accounts for 20% of this variability and the third component accounts for 15% of the data variance. Despite traditionally opting for a minimum number of components that represent at least 70% of the total variance, only the first 3 components were chosen – responsible for 76% of the total variance.

With the objective of analyzing the three configurations represented by the variability of the different variables, it is observed in Table 4 that component 1 is characterized by countries with high potential in emissions, high life expectancy and good infrastructure in sanitation and drinking water. Such results are pertinent due to the association of these factors as fundamental characteristics for countries to achieve the accumulation of skills and competences therein originated as a source of competitive advantage in the markets (Grassi, 2005). Some countries fit into this component, such as Canada, Germany, France and Sweden. Likewise, there is a conflict in which developing countries are not predisposed to subsidizing investments in environmental technologies due to higher pollution among developed countries. Similarly, large companies in more economically developed countries are reluctant to slow down their growth pace (Dechezleprêtre *et al*., 2011).

TABLE 4 – Profile of the main components (1990). ET = Environmental Technology; SP = Scientific Production; EM = Emissions of polluting gases; EX = Life expectancy at birth; SA = Sanitation; PD = Population density; DW = Drinking water; GP = GDP per capita.

Variables	Comp1	Comp2	Comp3
ET	0.2648	0.6097	0.089
EM	0.3855	0.0497	0.1424
SP	0.2155	0.6707	0.041
EX	0.4861	-0.1342	-0.1573
SA	0.4952	-0.2208	-0.176
GP	0.1262	-0.0836	0.6495
PD	0.1017	-0.1965	0.6838
DW	0.4765	-0.2521	-0.1579

SOURCE: The authors.

As for component 2, two important characteristics stand out: environmental technology and scientific production. Although policy strategies can exert direct effects producing different results across countries, they are mainly implemented by modifying existing policy instruments or creating new ones. Both observed variables allow us to state that technology policy uses investments that are directly focused on training researchers and on developing science (Kivimaa & Mickwitz, 2006). In this component we find the following countries: Brazil, China, Japan and United States.

Regarding component 3, the weight of the economic development and population density variables was higher than the other variables. Thus, it is likely that countries that fit this component promoted innovations in areas where they had dynamic advantages in important local markets and also enjoy a natural endowment or an accumulated skills base (Gomes & Corazza, 2013). The countries that can be characterized in this component are Bulgaria, Korea, India and Ireland. Table 5 presents the summary of characterizations by components, in all sample countries for 1990.

Regarding the year 2015, component 1 is represented by 36% of the total data variability (Table 6). The second component accounts for 23% of this variability and the third component accounts for 13% of the data variance. Despite traditionally opting for a minimum number of components that represent at least 70% of the total variance, only the first 3 components were chosen – responsible for 72% of the total variance.

TABLE 6 – Variance of the components (2015)

Components	Variance	
	Individual	Accrued
Comp1	36%	36%
Comp2	23%	59%
Comp3	13%	72%
Comp4	12%	85%
Comp5	8%	92%
Comp6	3%	96%
Comp7	3%	98%
Comp8	2%	100%

SOURCE: The authors.

According to the results in Table 7, in the component 1 group, countries such as Australia, Austria and Belgium with high levels of emissions,

TABLE 5 – Characterization of the three main components (1990).

Countries	Component 1	Component 2	Component 3
Argentina	-1.034351	-0.2487052	-1.237098
Australia	142.766	-0.3926399	-0.3236831
Austria	0.7306564	-0.6772912	-0.1518361
Belgium	0.9793237	-0.7561709	0.0123458
Brazil	-2.370473	0.3176614	-1.026674
Bulgaria	-0.5229743	-0.3246996	-1.725409
Canada	1.396398	-0.0926139	-0.8458932
China	-3.203624	1.422586	0.7854256
Cuba	-1.004215	-0.2669355	-1.161335
Czech Republic	0.5936627	-0.7198466	0.5991502
Denmark	0.690721	-0.675652	-0.4291998
Finland	0.6888483	-0.5883005	-0.6926317
France	0.9926561	0.1962813	-0.3063689
Germany	1.921067	1.801984	0.5102628
Greece	0.517223	-0.7209883	-0.984506
Holland	1.135751	-0.6016564	0.2370236
India	-5.901452	1.827339	1.899555
Ireland	0.2666271	-0.6695542	0.8408422
Israel	0.8492457	-0.8311065	-0.0086871
Italy	0.9555174	-0.2261243	-0.3429964
Japan	2.697.898	3.182062	0.6819794
Korea	0.2730777	-0.6968927	1.164996
Luxembourg	1.899266	-0.7230932	0.5219972
Malaysia	-0.4259448	-0.688008	0.3360727
Mexico	-1.802073	0.0994769	0.3429439
Moldova	-3.064019	0.4080561	0.0684892
Norway	0.6267168	-0.7559013	-0.5977623
Poland	-0.3733376	-0.215721	-0.3056293
Portugal	0.05139	-0.7742993	-0.0246374
Romania	-0.6342476	-0.4451214	0.7662708
Russia	-1.646395	0.2582571	-1.060736
Singapore	1.848434	-2.058014	4.660334

South Africa	-3.332525	0.9125923	0.033234
Spain	0.7423655	-0.6071578	-0.2447261
Sweden	0.699654	-0.5734013	-0.9191993
Switzerland	0.820496	-0.6415522	-0.3248592
Turkey	-1.693528	-0.1757968	1.017.729
Ukraine	-0.5091352	-0.2897252	-1.547633
United Kingdom	1.234222	0.5879955	-0.3924864
United States	3.479418	5.422677	0.1753365

SOURCE: The authors.

life expectancy, sanitation and infrastructure related to drinking water were observed. In component 2, again, countries that develop environmental technology and scientific production were observed. For the year 2015, some countries transitioned to this component, as was the case of China, India and Japan. Finally, component 3 was also characterized by the characteristic of a high economic development level, in addition to variables with significant weight such as scientific production and life expectancy. In this sense, the systemic character – which involves and helps guide and develop policies – encompasses diverse interests, that is, basically what contributes to a given policy being more successful than another is the interaction between public and private objectives. However, what will direct innovation towards the environmental sustainability objective necessarily consists in strengthening the State's role in advocating public objectives, despite the private sector being supported in terms of the necessary adjustments to changes in this direction (Freeman & Soete, 2008; Mazzucato, 2014).

In this way, it is possible to rescue the debate raised in the empirical framework, a moment when, between the 1970s and 1980s, there was growing concern with environmental damage, causing the first movement towards environmental innovations at a global level. In Germany, Japan and United States, the share of environmental patents was greater than the corresponding share of pollution abatement spending in GDPs. With that, from that period, a strong connection emerged between environmental regulation and innovation. In the three aforementioned countries, innovation responded

TABLE 7 – Profile of the main components (2015). ET = Environmental Technology; SP = Scientific Production; EM = Emissions of polluting gases; EX = Life expectancy at birth; SA = Sanitation; PD = Population density; DW = Drinking water; GP = GDP per capita.

Variables	Comp1	Comp2	Comp3
ET	0.2035	0.6133	0.1771
EM	0.3404	0.2899	-0.1579
SP	0.0455	0.6709	0.0535
EX	0.5234	-0.1061	0.2308
SA	0.5373	-0.1401	-0.1315
GP	-0.0184	0.051	0.9477
PD	0.116	-0.0988	0.0164
DW	0.514	-0.2157	0.0459

SOURCE: The authors.

to spending on reducing pollution, also boosted by environmental regulations. Furthermore, the generation of environmental patents in developing countries was also high, as in the case of Brazil. Transfers of environmental technologies were substantial in developing countries, especially in those located in East Asia, which opted to obtain technologies incorporated in pollution-fighting equipment, that is, innovation in reducing "end-of-pipe" pollution (Lanjouw & Mody, 1996).

Under this approach, the expansion of the "green" industry and the advantages of the transition to a sustainable energy system played an important role in reducing the CO_2 emission levels. Countries such as Canada, France, the United Kingdom and the USA were identified as having cutting-edge technologies within a portfolio of green technologies, that is, they identify the pattern of green technological accumulation in countries for climate mitigation, in addition to indicating a concern with controlling air pollution (Gomes & Corazza, 2013). It is worth highlighting the advances in the renewable energy sector, where China stands out. The sector accounts for a large share of production capacity in wind power, solar photovoltaics and smart grid technology. The emergence of China as a leader is yet another indication of the fundamental change in the techno-economic characteristics of global energy systems (Mathews, 2013).

Table 8 presents the summary of characterizations by components (scores), in all sample countries for the year 2015.

TABLE 8 – Characterization of the three main components (2015)

Countries	Component 1	Component 2	Component 3
Argentina	-0.5215397	-0.7802174	-0.1163472
Australia	1.645349	0.1210173	-0.4708577
Austria	0.7657413	-0.7828103	-0.374951
Belgium	0.8472543	-0.6787989	-0.1130664
Brazil	-1.469701	-0.403159	-1.229854
Bulgaria	-1.045554	-0.5662442	0.4005088
Canada	1.477364	0.3275784	-0.6573345
China	-1.839487	3.969953	1.017824
Cuba	-1.157725	-0.6138711	0.5978216
Czech Republic	0.5638642	-0.53664	0.5104468
Denmark	0.5973594	-0.8115869	0.0034034
Finland	0.8986054	-0.6920837	-0.3623099
France	0.7683278	-0.1329637	-0.0283784
Germany	1.262.958	1.225978	-0.2717408

Greece	0.5895565	-0.9196497	-0.2756402
Holland	0.9867853	-0.3677435	-0.1018399
India	-5.178717	1.210.518	1.207452
Ireland	-0.2612487	-0.2934246	4.750557
Israel	0.9672402	-0.7866826	-0.2825801
Italy	0.6648042	-0.3430489	0.0002155
Japan	1.913722	2.394.198	-0.1484203
Korea	1.605722	1.004534	-0.0757502
Luxembourg	1.619676	-0.158426	-0.297308
Malaysia	-0.3890437	-0.3316346	0.0556313
Mexico	-1.108895	-0.6326202	0.0001159
Moldova	-4.265053	0.0448527	-0.5129549
Norway	0.9525446	-0.671011	-0.1606276
Poland	0.0763717	-0.419011	0.2879617
Portugal	0.4378116	-1.010682	0.2199133
Romania	-1.248835	-0.7054501	0.6425403
Russia	-1.058302	0.4051823	-1.451264
Singapore	1.930646	-1.252961	0.0438733
South Africa	-4.042569	0.6763371	-1.177368
Spain	0.7536378	-0.6072248	0.6429675
Sweden	0.6167083	-0.8496785	0.4951217
Switzerland	0.7288054	-0.9708178	-0.1140473
Turkey	-0.3492633	-0.6051577	0.4499577
Ukraine	-1.826315	-0.4202968	-2.778405
United Kingdom	0.7995434	0.1200843	0.0170865
United States	2.291847	5.843663	-0.3423523

SOURCE: The authors.

Thus, based on the Principal Component Analysis (PCA), it was observed that the configurations between the countries were very different between both years considered (1990 and 2015). Parallel to the comparative and static result, verified by PCA in such specific years, the panel data model was estimated with the objective of investigating the dynamic and time evolution in the five-year intervals distributed over the period from 1990 to 2015.

For the applied econometric analysis, firstly, the empirical model specified in Section 4.2 (Equation 1) was estimated according to the following estimators: Within: One-way + Two-way, One-way (individual and time), Two-way, Pooled, First Differences and Between. From the results, the choice of the best random effect model and the best fixed effect model is indicated among the one-way time, one-way individual and two-way (time + individual) before performing the Hausman test. The test formulated by Hausman has an asymptotic χ^2 distribution if the null hypothesis is rejected (H_0: random effects are consistent and H_1: random effects are not consistent). The conclusion was that the random effects model is adequate and preferable. In this case, the Hausman test did not reject the null hypothesis that random effects are consistent and indicated that the best choice is random effects modeling.

Based on the results in Table 9, the result of estimating the random effect models provides information on the variance of the error components, one referring to the cross-sectional or individual-specific component represented by individual, the other idiosyncratic term, which varies with cross section and over time (Within: One-way + Two-way). Therefore, by using the Hausman test it was possible to decide for the random effect model. In order to control the problems related to endogeneity (mentioned in item 4.2) and given the possibility that the independent variables are correlated, we opted for estimation using the method of instrumental variables by least squares in 2-stage with error component (EC2SLS).

Thus, the endogenous variable was the pollutant gas emissions indicator, and the instrumental variables used were as follows: life expectancy, sanitation, population density, GDP *per capita* and the drinking water indicator. Nevertheless, the motivation for using instrumental variables was justified according to the problem caused by the omitted variables. In other words, when faced with the prospect of biases from omitted variables (or unobserved heterogeneity), it is possible to ignore the problem and suffer the consequences of biased and inconsistent estimators. Therefore, use of the instrumental variables method that recognizes the presence of the omitted variables consists in leaving the unobserved variables in the error term, instead of only estimating the model by means of the OLS (pooled) method. Thus, estimation using the method of instrumental variables by 2-stage least squares with error component (EC2SLS) made it possible to define a set of instruments that met the criteria of being strongly correlated to the endogenous variables, therefore enabling to reduce the endogeneity problem.

The estimation with panel data used explanatory variables such as the level of emissions and scientific production to explain the development of environmental innovations. The estimation carried out using the method of instrumental variables, by least squares in 2-stage with error component (EC2SLS) allowed to minimize the endogeneity problem, instrumentalizing the emissions variable.

TABLE 9 – Model results for One-way effects (Individual and Time), Two-way, Pooled, First Differences and Between

One way Individual			***One way Time***			***Two ways***		***Pooled, First Differences (FD), Between***			
	Fixed effects	Random Effects		Fixed effects	Random Effects		Fixed effects		Pooled	FD	Between
SP	0.00001**	0.00001**	SP	0.00001**	0.00001**	SP	0.00005**	SP	0.0001***	0.00002***	0.0001*
	(0.00001)	(0.00001)		(0.00003)	(0.00002)		(0.00002)		(0.00002)	(0.00001)	(0.0001)
EM	0.232	0.249	EM	0.453***	0.421***	EM	−0.563	EM	0.413***	−0.108	0.539
	(0.200)	(0.203)		(0.160)	(0.146)		(0.490)		(0.143)	(0.167)	(0.356)
Constant		−0.015	Constant		-3.978***	Constant		Constant	−3.744***	−0.137*	−4.898
		(1.738)			(1.473)				(1.401)	(0.072)	(3.727)
Observations	240	240	Observations	240	240	Observations	240	Observations	240	200	40
R^2	0.162	0.173	R^2	0.486	0.478	R^2	0.054	R^2	0.474	0.085	0.506
R^2 adjusted	-0.012	0.166	R^2 adjusted	0.471	0.473	R^2 adjusted	−0.171	R^2 adjusted	0.470	0.076	0.480
F	13.066***	14.505***	F	19.398***	22.453***	F	11.488***	F	23.104***	10.895***	4.378

Hausman test: p-value = 0.847 Hausman test: p-value = 0.69

Dependent variable: Environmental Technology
NOTE 1: *p<0.1; **p<0.05; ***p<0.01

NOTE 2: The Standard Deviation is included between parentheses.

SOURCE: The authors.

Nevertheless, the set of instruments consisting of sociodemographic variables was validated by the Sargan test, which indicated validity of the instruments at 5% significance, indicating that the set of instruments used is consistent. The results can be seen in Table 10.

TABLE 10 – Estimation results by the method of instrumental variables (EC2SLS).

Dependent Variable: ET	
	EC2SLS
SP	0.000156***
	(0.00002)
EM	0.4000478***
	(0.16994)
Constant	-1.33179
	(1.5223)
Observations	240
Hausman test: 0.34	
Sargan test: 17.813**	
Instrumented variable: EM	
Instrumental variables: EX; SA; PD; DW	

NOTES: Significance levels: ***: Significant at 1%; **: Significant at 5%;

The Standard Deviation is included between parentheses.

SOURCE: The authors.

According to the results based on the model estimated by the method of instrumental variables (EC2SLS) (Table 10), both polluting gas emissions and scientific production are significant for the production of environmental technology in the sample countries. CO_2 gas emissions refer to the levels and damage caused by economic activity to human health and the environment. Thus, despite the stabilization and reduction of gas emissions by the most polluting countries over time, the technological revolution is more than necessary in the long-, medium- and short terms (Barret, 2009).

Another important point regarding use of this indicator refers to the issue of environmental regulations. Due to the complexity of considering individual indicators for each country on the intrinsic factor of environmental regulations, the indicator can also be considered as an indirect proxy of environmental standards (Crespi, 2013). Therefore, countries that emit high levels of CO_2 gases can also be affected by strict and effective environmental regulations, in which they are encouraged to develop environmental technologies (Crespi, 2013). Thus, based on the results presented, although the characteristics between developed and developing countries are different, the environmental innovative capacity across countries has a strong relationship with CO_2 gas emissions.

As for scientific production, it is known that the process of generating new technologies encompasses an increasingly systemic character, in which the strengthening of the relationship between economic agents, research institutions and universities is essential to the formation, development and consolidation of National Innovation Systems (NISs) (Lanjouw & Mody, 1996; Kivimaa & Mickwitz, 2006; Kemp & Pearson, 2007; Kemp & Pontoglio, 2011; Kesidou & Demirel, 2012). In this sense, from the different stages of the NISs and their different dimensions (scientific, economic, environmental), it is possible to observe that environmental technological development should not be analyzed as an isolated phenomenon in space and time, but as a result of several cumulative paths, historically constructed according to institutional and political specificities.

In other words, environmental technologies are currently more developed in countries with high economic development, and are not diffused in the economic world at the necessary speed and scale (Haščič *et al*., 2010). However, it should be noted that the effort and production of environmental technologies in developing countries, even if to a lesser extent, are more specific to the needs of these economies. However, it is understood that these technologies are not produced on a larger scale due to scientific and economic structural obstacles, in addition to the lack of incentives for their development.

6. Final considerations

Interactions between economic agents, research institutions and governmental agencies stimulate actions in favor of the countries' ability to develop environmental innovation. For there to be an environment conducive to the development of these innovations, it is necessary for nations to create and promote conditions for an adequate infrastructure, with the aim of improving existing technologies and instigating the development of new ones. The question addressed became the objective of this article, that is, to identify specific characteristics that lead to environmental technological development among developed and developing nations. In this case, the results of this article revealed that economic advances are, in a way, balanced between maintaining economic growth and environmental susceptibility, referring to the impacts of the environment in the medium- and long terms. Therefore, environmental innovations are understood as the most efficient and capable way of maintaining the balance between economic growth and the search for better quality of life.

With regard to scientific and technological asymmetries, there was high capacity for environmental technological development on the part of developed countries, mainly coming from the United States. It is worth emphasizing that this result indicates that the asymmetries between development of the countries may be linked to the maturity degree of the nations' National Innovation System. The analysis that developed countries are the most likely to make efforts towards the production of environmental technologies was confirmed, not only in the case of the United States, but also in other developed economies, such as Germany and Japan.

However, for the generation of technological knowledge to become increasingly solid, it is fundamental to build an integrated network of actors and an adequate atmosphere that allows reducing uncertainties and endogenizing the technological progress to be acquired. The highlighted actors represent universities, governments and research centers, in addition to the engagement of companies that provide improvements of existing technologies and development of innovations. In other words, efforts to promote cleaner and more sustainable technologies involve broad factors that are difficult to measure and highly complex.

In the article, the Principal Components Analysis methodology identified significant differences in the characterizations between countries such as Germany and Japan. Furthermore, in countries such as Canada, Denmark and Spain, characteristics that reflect successful technological and infrastructural policies were observed, but which still do not fully encompass more incisive responses in the environmental aspect. After the estimations carried out with the panel data methodology, joint environmental technological efforts were seen, especially from countries such as Brazil, China, India, Japan and the United States. However, it was also found that scientific production was accompanied by continuous emissions of polluting gases in favor of environmental technological development.

Thus, it is believed that the promotion of environmental technologies - despite having contributed to the countries to evolve in the scientific and economic development of the activities of their National Innovation Systems - still remains far from the priority agenda on environmental issues, in relation to the countries included in the sample of the current study.

In general, the diversity of policy proposals and the common objective of developing environmental technologies will essentially depend on the orientation of technical changes in the conduct of specific goals and objectives. In this regard, there are several ways to encourage and subsidize the development of environmental technologies. Likewise, policies that enable evolution of these technologies through economic instruments or via direct regulation of tradable emissions, for example, are some of the decisions that should be widely debated across the economies.

Finally, the article reveals the need to update technological policies more focused on mitigating environmental impact, especially industrial ones. Likewise, in this case the changes must be thought of not only from a specific point of view, of a specific problem, but as a process of slow, gradual and long-term results, benefiting the adoption of better strategies in favor of the development of clean technologies and society's quality of life.

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