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Artigo

Macro-comparative analysis of environmental innovation (1990, 2000 and 2010)

*Rosa Livia Gonçalves Montenegro** https://orcid.org/0000-0001-8383-5131

*Gustavo Britto*** https://orcid.org/0000-0002-5285-3684

*Leonardo Costa Ribeiro**** https://orcid.org/0000-0002-7772-9313

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Abstract

The aim of the present work is to assess and capture the specific interactions related to the environment and technology of developed and developing countries, in 1990, 2000 and 2010. The database used factors related to environmental innovation activity, degree of economic development, conditions of infrastructure, alternative energy production capacity, gas emission level and scientific ability of the economies. The methodology covers a method unexplored in literature about innovation, qualitative comparative analysis (QCA). Applying the technique for each year, the results provide a static analysis of possible changes in specific configurations of each country in this time frame. The results indicate that the configurations that lead to environmental innovation activity are represented by good conditions for scientific, technological and economic capacity.

Keywords | Qualitative Comparative Analysis; Environmental and Technological Indicators; Environmental Capacity of Countries

JEL Code | O3; O31; O33

* Universidade Federal de São João del Rei (UFSJ), São João del Rei (MG), Brasil. E-mail: rosalivia@gmail.com

** Universidade Federal de Minas Gerais (UFMG), Belo Horizonte (MG), Brasil. E-mail: gustavo@cedeplar.ufmg.br

*** Instituto Nacional de Metrologia, Qualidade e Tecnologia(Inmetro), Rio de Janeiro (RJ), Brasil. E-mail: leonardocostaribeiro@gmail.com

Análise macrocomparativa da inovação ambiental (1990, 2000 e 2010)

RESUMO

O objetivo principal do trabalho é compreender a influência e captar as configurações relacionadas ao meio ambiente e à tecnologia dos países desenvolvidos e em desenvolvimento que compõem a amostra, nos anos de 1990, 2000 e 2010. A base de dados consiste na utilização de fatores relacionados à atividade inovativa ambiental, ao grau de desenvolvimento econômico, às condições de infraestrutura, capacidade de produção de energia alternativa e nível de emissão de gases CO_2 e à capacidade científica das nações. A metodologia aplicada aborda um método pouco explorado na literatura sobre inovação e meio ambiente: a técnica de análise qualitativa comparativa (QCA). Ao aplicar a técnica, para cada ano, os resultados fornecem uma análise de eventuais mudanças nas configurações específicas de cada país nesse intervalo temporal. Os resultados revelaram que as configurações que levam à inovação ambiental são representadas por boas condições de capacidade ambiental, científica e econômica.

PALAVRAS-CHAVE | Análise Qualitativa Comparativa (QCA); Indicadores Tecnológicos e Ambientais; Capacidade Ambiental dos Países

CÓDIGOS-JEL | O3; O31; O33

1. Introduction

Global climatic policies and the recognition of environmental threats have featured as urgent issues in international discussions starting from the second half of the twentieth century (ARRUDA; CARVALHO, 2014). Concern from governments and institutions stemmed from scientific observations on environmental modifications caused by technological advances. The pursuit for a development pattern which could be replicable for future generations became a research topic for several economies. In such a context, and as economic growth and world economic integration took place, aggressions to the environment became more serious and more visible, both in core and peripheral countries that comprise global capitalism.

The justification for the present study, which refers to the environmental capacity of countries, and its analysis, related to environmental innovations, is the conciliation between the promotion of technology capable of guaranteeing the alleviation of environmental impacts, greater economy and energetic efficiency, better quality of life to the population, and the economic growth of countries. With the rising concern about environmental problems around the world, the pattern of economic development observed over the twentieth century has faced drawbacks which are not easily overcome. One of them is the fact that a dissemination of environmental technology linked to a new pattern of institutional change is not feasible in the short-term (FREEMAN, 2002).

In this respect, this paper seeks to understand the influence and capture the configurations related to the environment and technology of developed and developing countries which comprise our sample, in the years 1990, 2000 and 2010. To this end, we draw on qualitative comparative analysis (QCA), which allows, in exploratory fashion, to understand the nature of simultaneous relations among developed and developing countries and identify the connection with innovations and the environmental capacity of the countries under scrutiny.[1] Moreover, the analysis aims to identify and present the configurations of the 40 countries (both developed and developing) which make up the sample, by using indicators related to technological and environmental conditions and to economic and scientific capacities, in the years 1990, 2000, and 2010. By applying, for each year, the results derived from the fuzzy set QCA (fsQCA) technique here adopted, "photographs" of occasional changes in the specific configurations of each country over the time

1 Broadly, the environmental capacity of countries refers to the ability constructed and developed by a society to observe, analyze, and rectify its environmental problems (WEIDNER, 2002).

span (static analysis) are provided. These alterations might confirm whether a country has become more similar or more heterogeneous in comparison to another according to the variables that are specified in this paper. Similar countries shall naturally comprise the same group, while heterogeneous countries shall form other characteristic groups. Therefore, a small number of groups generated by the forty countries in this research would indicate a relatively high number of economies with similar behavior.

Besides this introduction, this work is comprised of four more sections. In the second one, the concept and characteristics of environmental innovation are presented. Then, the third section features the methodology and the description of the database. In the following section, the results of the statistical procedures are examined. Finally, section 5 presents the conclusions of the research, highlighting its contributions, the main outcomes of different configurations among developed and developing nations, and potential research advances and extensions.

2. Environmental innovation as a concept

Challenges posed to technological development conform the creation of strategies which, in turn, lead to specific solutions and to the decrease in environmental impacts of industrial activities.[2] It is expected that solutions made available by environmental technologies be quickly intensified in the course of 10 to 30 years (TGCII, 2014). The need to establish strategies in benefit of the environment has motivated governments to develop and implement transition policies from an industrial paradigm of traditional economy to a model which is more in line with principles of sustainable development.

The term sustainable development,[3] according to the World Comission on Environment and Development (CMMAD, 1988), characterizes the satisfaction of the needs of the current generation without compromising the capacity of subsequent generations.

Although the concept of sustainable development appears to be simple, it is complex and is shaped by the concern with a disorderly exploitation of resources,

2 Other productive activities also cause severe environmental damage, such as the use of agrochemicals, fertilizers, and excessive irrigation in agriculture.

3 The concept of sustainable development acknowledges that the capacity of an economic system to satisfy long-term human needs will depend on the viability conditions of the environment and of technologies connected to consumption and production. In this case, technologies become the essential part of technological changes, be it through the quick dissemination of pre-existing dynamic technologies, or through innovative activities which develop new technologies (FREEMAN; SOETE, 2008).

which also underscores the importance of technological development and the involvement of institutions in catering for the needs of current and future generations (CMMAD, 1988). Additionally, the concept of sustainable innovation can also be understood by merging the two terms which comprise it; it refers to that which creates added value without compromising the capacity of future generations and meets, in the long-term, sustainable development.

In turn, the definitions of environmental innovation available in literature exhibit a wide diversity of meanings, since they incorporate, besides the issue of environmental technology, different inherent characteristics of the innovation and environmental impact alleviation processes. Alongside technological development, it can be said that the changes in the conceptualization of environmental innovation are relatively new (LUCCHESI, 2013; ARRUDA; CARVALHO, 2014), and they allow for various meanings to be incorporated into the subject area of environmental technology.

In this respect, it is easy to find words that are similar to environmental innovations, such as: eco-innovations, ecotechnologies, environmentally friendly technologies, sustainable technologies, green technologies, among others. The terms, despite presenting specific characteristics, are widely used as synonyms (CARRILLO-HERMOSILLA et al., 2010). Specifically, eco-innovations can be defined as innovation systems oriented towards sustainable development, in which new products and processes that contribute to the reduction of environmental cost and/or to specific environmental objectives are developed (RENNINGS, 2000; FUSSLER; JAMES, 1997).

Rennings (2000) also points out that eco-innovations reduce environmental impact caused by production and consumption activities and can be defined as being the result of the interaction between agents and actors (companies, universities, and research centers) capable of developing and applying new ideas in products and processes that contribute to the alleviation of environmental impact. Likewise, Arundel and Kemp (2009) characterize eco-innovation as the production, assimilation, or exploration of a product, process, service, or management operation in which the results imply a reduction of environmental impact.

The definition of environmental innovation which more closely resembles its purpose and which will be used in this paper is defined as all the production, exploration, and assimilation of a product, production process, services, or management methods, which is new (in development or adoption) to the organization, and which implies, along its life cycle, a reduction in environmental impact, pollution, and other negative effects of the usage of resources (including energy) in comparison to corresponding alternatives (MEI, 2008).

One of the first examples of research on environmental innovative activity was undertaken by Lanjouw and Mody (1996), who examined the relation between the number of patents granted and the strictness of environmental policies, measured in terms of expenditure on pollution costs, in Japan, United States, Germany, and some developing countries, such as Brazil, India, and Mexico. Data on patents refer to innovations which minimize pollution impact (end-of-pipe) and the ones which reduce the quantity of contaminants in their production, except alternative energy technologies. The authors discovered that, in the period between 1971 and 1988, the costs of reducing pollution positively affected the number of patents granted, albeit with a one- or two-year gap. The study did not successfully show some of the control factors on patenting, that is, which are the susceptible elements that affect end-of-pipe innovation. However, it emphasized that the goal of environmental patenting for developed countries is the protection of their market and that developing countries are advancing towards adaptive innovations, especially regarding technologies for water pollution reduction.

Brunnermeier and Cohen (2003), having Jaffe and Palmer's work (1997) as a basis, investigated the diversion of innovations in general to environmental innovations. To do so, the authors used information about industrial sectors in the United States and empirically analyzed the determining factors of environmental innovations. Using data panel, the results revealed that environmental innovations (measured by the number of patents granted to the industry) respond to increases in spending on pollution costs, which is contrary to the findings reported by Jaffe and Palmer (1997). However, the increase in inspection and execution activities related to the existence of regulation do not stimulate industries to innovate. Empirical evidence has shown that environmental innovation is more susceptible in sectors which are internationally competitive.

Thus, if, on the one hand, economic growth can increase well-being, on the other, it comprises many costs involved in the process. In the case of clean technologies, the development of an innovation for the company's own use is usually not profitable due to the high costs embedded in, for instance, installations of pollution control and waste management equipment (KEMP; SOETE, 1992). In order to investigate and understand the complex nature of simultaneous relations between countries and their dynamics related to innovation and environmental capacity, we proceed to present the methodology and database used for the application of the qualitative comparative analysis technique.-

3. Methodological approach

In methodological terms, the determinants of the environmental capacity of countries are usually analyzed using econometric or econometric-spatial methods. Equations are estimated from both methods and, from the equations, it is possible to compute an average value for each observation (i.e., a score). Thus, influences from these determinants represent averages of the relations or influences of variables on all observations.

Like statistical techniques of simultaneous data analysis, namely, multivariate analysis techniques, fsQCA also simplifies and groups observations naturally, exactly because it provides the frequency with which specific configurations occur between observations in a data structure. That is, countries can exhibit the same specific configuration (interaction between determinants) and, thus, they can be grouped in a distinct set in relation to other countries.

3.1. Fuzzy set qualitative comparative analysis (fsQCA)

Qualitative comparative analysis has the objective of analyzing and understanding the phenomenon of causality, that is, exploring complex relationship patterns. QCA is particularly suited to analyze configurations which are related to innovation and, since it is a relatively new method, it has not been used to a great extent in empirical applications on innovation and economic research areas (GANTER; HECKER, 2014). The technique is different from other statistical methods, which start from a great number of cases as a premise, and it must be developed according to random variables and with a large amount of information (RIHOUX; RAGIN, 2009).

The QCA technique and its applications were developed with the purpose of treating a small number of observations (small-N) and providing a macro-comparative approach. QCA exhibits particularities, and its procedures, as well as its terminology, are different in comparison to other techniques. For instance, explanatory variables are depicted here as *conditions*; the dependent variable is termed *outcomet*; observations, in our case, of developed and developing countries are called *cases*; and the resulting equations that follow analysis are referred to as *solutions*.

In the analysis of present conditions, criteria based on fsQCA will be used. The objective is to use this method with the goal of exploring specific configurations for each of the forty countries in three specific time frames (1990, 2000, 2010), whose information is, to a degree, latent in the statistic techniques of inference and multivariate analysis.

3.2. Database and calibration

In the present paper, QCA has the objective of observing whether, in the three years under scrutiny (1990, 2000, 2010), there was a significant change in results and conditions presented in the solutions for the three periods and which may be the possible causal combinations which lead to a desired outcome. Similarly, QCA allows for the identification of the 40 cases[4] (countries)[5] and of whether environmental innovative activity occurs, in addition to characterizing the economies according to the specified conditions and detecting possible ways through which the same set of conditions would affect environmental innovations.

Before describing in greater detail the procedures of the QCA method, it is necessary to determine the definition of sets, which represent the same analysis for the three years. The specification (labeling) of conditions must be suitable to the objectives of the investigation and its meanings, whose requirements are clearly expressed so as to specify its real meaning when in relation to a given set (Table 1).

In this case, in order to investigate whether environmental innovative activities are more likely to happen in developed countries, the set of conditions was defined in accordance with perspectives about the undertaking of environmental innovation. The database used was built from the combination of different sources, such as: patent data from the European Patent Office (EPO); data from scientific papers, Gross Domestic Product (GDP), alternative and nuclear energy production, sanitary conditions extracted from the World Bank database; and, finally, information on CO_2 emissions extracted from the Carbon Dioxide Information Analysis Center and from the World Bank database. The indicators we present in Table 1 were selected from a set of Green Growth Indicators devised by OECD (2014).

For the intended outcome (proxy of environmental innovations), we used the number of patent applications by each country which comprises the sample, divided by 1 million inhabitants. In other words, patents are registered through an international patent application and, consequently, it is possible for one application

4 The choice of the 40 countries is justified by the complexity of covering world data for specific variables.

5 The developed and developing countries analyzed here are: Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Cuba, Czech Republic, Denmark, Finland, France, Germany, Greece, India, Ireland, Israel, Italy, Japan, Luxembourg, Malaysia, Mexico, Moldova, the Netherlands, Norway, Poland, Portugal, Romania, Russia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom, and the United States.

to be valid for different countries. It is necessary to highlight that the main proxy used to capture influences from environmental innovation among developed and developing countries were environmental patents (A).[6] The utilization of environmental patents was based on a great diversity of empirical research that use them as proxies to measure the technological capacity of countries, as well as to analyze the development of environmental activities in economies under investigation.

In turn, indicator (E) refers to the percentage of all alternative and nuclear energy[7] produced in all sample counties, based on information from the World Bank. The energy used for the construction of this indicator is the one that does not produce carbon dioxide when generated, such as hydroelectric, nuclear, geothermic, solar, among others. Then, the purpose of this indicator is to provide information and characteristics that are pertinent both to environmental and technological solutions and which can favor the dissemination of new energy sources (MOWERY et al., 2010). In this regard, Mowery et al. (2010) point out that the devising and production of alternative energy technologies still take a long and complex learning process, with incremental improvements and an intense development monitoring in a wide array of biological areas.

As regards the indicator G, it represents the ratio between a country's total CO_2 emission and its population. The indicator was measured in metric tons of carbon and the source of data was the combination of the database made available by the Carbon Dioxide Information Analysis Center and the World Bank database. CO_2 emissions reflect current levels of economic activity, that is, the indicator also measures the damage stemmed from economic activities to human health and/or the environment.

Indicator S, in turn, indicates the percentage of a country's population that make use of sanitary installations, that is, installations linked to well-being and quality of life, such as sanitary sewerage and basic sanitation,[8] extracted from the World Bank database. Such indicator represents a variable of infrastructure that is common to all countries that share a minimum level of development. However, the main objective of adding this variable is, generally, to establish and understand

6 For the classification of environmental patents, the IPC system and its respective technological classes were used, which also enabled the identification of patents according to seven strategic areas, available on the IPC Green Inventory. The seven areas are: (a) Production of alternative energy; (b) Transport; (c) Energy conservation; (d) Waste management; (e) Agriculture/Forestry; (f) Administrative, Regulatory, and Project issues; and (g) Nuclear energy generation. For further details: <http://www.wipo.int/classifications/ipc/en/est/>

7 Alternative energy is also referred to as renewable energy.

8 The term basic sanitation usually includes sanitary exhaustion (sewage collection and treatment) and corresponding services.

the relation between the environmental innovative capacity and minimum levels of infrastructure in the sample countries.

In turn, indicator P represents the GDP per capita of countries (Table 1). The variable, measured in constant 2005-dollar values, has the World Bank database as source and aims to assess the connection between the degree of economic development and the environmental innovative capacity of sample countries. According to Furman et al. (2002), the level of technological development of a country is directly associated to its innovative results, i.e., the level of environmental patenting is a consequence of a country's investment in mid- and long-term innovation and improvements in technological and environmental policies, considering, thus, countries with significant levels of economic development.

Finally, indicator C can be defined as the number of scientific and technical journal papers related to these areas: physics, biology, chemistry, mathematics, clinical medicine, biomedical investigation, engineering, technology, Earth sciences, and space science, divided by a million inhabitants. The indicator, extracted from the World Bank database, aims to assess the influence of scientific activity exclusively via its capacities linked to environmental technological development.

Therefore, the use of QCA allows us to consider not only the scientific or even purely economic production (such as the development level of countries) but also other contributing factors, other conditions which might foster or slow down environmental innovative activities in the cases under study.

TABLE 1
Typologies used in QCA: results and causal conditions

QCA terminology	Acronym	Definition of results and conditions
Outcome	A	Set of countries with environmental innovative activity
Causal conditions	E	Set of countries which use alternative and nuclear energy
	G	Set of countries which emit pollutant gases (CO_2)
	S	Set of countries which exhibit adequate infrastructure conditions
	P	Set of economically developed countries
	C	Set of countries with scientific production

Source: Authors' own.

After the causal conditions for the phenomenon (outcome) that we seek to observe are defined, it is necessary to attribute membership degrees to each condition of each set for the three years that are analyzed. Via the calibration process, it is possible to attribute membership scores, based on the calibration method. "The key element to understand fsQCA is that, unlike conventional variables, the fuzzy set has to be calibrated. This need arises due to its superiority in relation to other methods, as the fuzzy set offers an intermediary path between qualitative and quantitative analysis" (RAGIN, 2008b, p. 175). Thus, from focusing on the importance of establishing certain properties and limits to the conditions, we opted for a direct calibration method in the construction of the fuzzy set for the results and conditions of our analysis. The direct method, used in this article,[9] comprises three qualitative anchors (the threshold for full membership, the threshold for full nonmembership, and the crossover point) that aim to structure conditions and results in a fuzzy set.

Then, with the indicators already calibrated, it is important to establish relations between the environmental and technological production in terms of the specified set of conditions (Table 1). It is worth stressing that, despite all the precautions taken in the elaboration of a data set that is comprehensible and feasible, information might exhibit imperfections and, therefore, some possible reservations need to be addressed.

Firstly, it is possible to assess, with fsQCA, whether there is a certain level of consistency in relation to a given subset by using this formula:

$$Consistency(X_i \leq Y_i) = \frac{\sum \min(X_{i,}Y_i)}{\sum(X_i)} \tag{1}$$

In which X_i is the degree of association in set X ; Y_i is the degree of association in set Y ; and $(X_i \leq Y_i)$ is the relation of the given subset (*min* imposes the selection of the two lowest scores).

Consistency, in turn, reveals the degree to which the relation between causal conditions is close to the desired outcome. In other words, consistency measures the degree of association of cases, given a combination of conditions according to the outcome (environmental innovative activity) (RAGIN, 2006). Moreover, the (high or low) value of consistency indicates whether there are specific causes or a combination of causal conditions that constitute one of the several possible pathways for the result.

9 For more information and details regarding calibration in the direct method, see Ragin (2008b).

The concept of coverage is different from that of consistency, since the first assesses the empirical relevance of the presented subset. In other words, coverage measures the extent to which the causal combination is responsible for the outcome instances, and well as measuring the extent to which the outcome can be explained by the combination, causal condition. When there are many pathways for the same outcome, the coverage of a given causal combination can be low, which implies that a high coverage value can represent a causal combination that is of significant empirical relevance. In short, both measures (coverage and consistency) are used to assess whether the condition of a set of relations is necessary but not sufficient for an outcome whose occurrences constitute the circumstances of a cause.

For instance, equation 2 below shows the measuring of coverage of the fuzzy set. The calculation of coverage can also be applied to assess the necessary conditions in cases when the outcome is a subset of the cause (RAGIN, 2006). The measure of relevance of X_i as a necessary condition for Y_i is given by the coverage degree of X_i by Y_i, according to this equation:

$$Coverage\ (X_i \geq Y_i) = \frac{\sum \min(X_i, Y_i)}{\sum (X_i)} \tag{2}$$

The interpretation for the analysis of coverage can be explained when the coverage of X by Y is low, then the effect of X in Y is negligible. Such an outcome means that a small coverage corresponds to an irrelevant effect, or that the condition is not necessary. We stress as well that the calculation of consistency for a relation of sufficiency (equation 1) is similar to the calculation for (relevant) coverage for a necessary relation (equation 2).

For the final fsQCA solution, the elaboration of the Truth Table is necessary, simplifying the analysis according to cases (observations) characteristics, enabling more diversified studies (i.e., more complex research) to identify the most common configurations and those that are less likely to happen (KENT, 2008). Then, after the fuzzy set is established, there is the elaboration of the Truth Table, representing any possibilities of configuration in which the number of rows is given by 2^k; k[10] being the number of attributes, causal conditions (GANTHER; HECKER, 2014).

The translation of the fuzzy set to the Truth Table represents statements on the causal conditions formed by the fuzzy set. From this translation, two pieces of information can be observed when analyzing the Truth Table. The first one is the identification of the number of cases that show tight association in each

10 In the case of the fsQCA of this article, there are 5 conditions under study (k=5) and 32 possible condition combinations.

causal condition or in each combination of causal conditions. The second piece of information, in turn, refers to the empirical consistency for each condition, that is, it is possible to observe the degree of association of the condition as a subset of the outcome.

Moreover, the analysis of conditions in the Truth Table requires caution, for the conditions can be less clear-cut since each case can represent a partial association in all rows of the table (i.e.in each causal condition). Thus, it is necessary to examine the distribution of association scores by means of causal combinations, because if most of the cases present null value (0) or small association in the combination, it would be utterly unnecessary to consider the relation of combinations to the outcome.

The key factor in the analysis of the final solution of the QCA, therefore, is the establishment of a threshold number of conditions (explanatory variables). For such, certain criteria need to be established based on the knowledge of the researcher and taking into consideration the analysis of combinations of the causal conditions. In short, when the number of causal conditions is too high, the probability of not observing present circumstances in the combination of causal conditions is higher, and greater is the number of rows in the Truth Table which are not be observable (RAGIN, 2004). In this sense, before the analysis of the final QCA solution, the logical minimization of the table truth is required, due to both the specification of the frequency threshold and the consistency crossover point, generally establishing the cut-off value of 0.8 on average (RAGIN, 2008a, 2008b).

In short, the investigation on different combinations of causal conditions for the desired outcome – in this case, environmental innovations – allows for a wider configuration of their relations and strategies concerning different stages of the environmental innovative activity among the economies under study.

4. Discussion of the results

Before we describe the results[11] stemmed from fsQCA and the descriptive analysis of the outcome (Appendix), we highlight that one of the objectives of using QCA, beyond the analysis of the behavior of the causal combinations during the years, is to understand how these different conditions inserted through different dimensions foster environmental technological activity. The first stage before the application of

11 Three different software programs were used in the execution of the procedures described hereinafter: namely, TOSMANA, Stata 11, and fsQCA.

QCA is the calibration[12] of variables for the fuzzy technique. After this procedure, the first configurations found from the distinct conditions among countries are observed. The results exhibited in Table 2 show all the configurations for each set of causal conditions. The interpretation of these configurations has the objective of understanding the intensity of the conditions provided, that is, the magnitude of the conditions that can be represented by using upper- and lower-case letters, referring, respectively, to the high or low intensity of conditions.

The configuration of conditions provided on Table 2 refers to the interaction between determinants that lead to the outcome for a given country. The sets of configurations show that, in 1990, 15% of the countries tried a combination of causal conditions in above-average levels (ECGSP): Belgium, Canada, Finland, Japan, the United Kingdom, and the United States. Such configuration indicates that, in these countries, in the year 1990, for the undertaking of environmental innovative activity, the combination of high levels of alternative energy usage, substantial scientific production capacity, high level of emission of pollutant gases, good infrastructure, and high level of economic development were indispensable elements and comprised the best conditions for fostering environmental innovative activity. In the same year, developing countries exhibited different configurations. However, it was noticeable that the participation of a considerable infrastructure (S), as in the case of Brazil, strong scientific (C) and economic development (P) structures, especially in China and India, indicates factors conducive to the strengthening of their innovative activities. The exception of outcomes in developing countries was South Africa, which presented high emissions of pollutant gases (G) as a configuration for environmental innovative activity.

In the year 2000, the most common configuration (ecgSp), shown by 20% of the countries, was that comprised of low usage of alternative energy and nuclear power, small scientific production, low levels of gas emissions, low degree of economic development, but considerable infrastructure level. The countries that fit this configuration were: Argentina, Cuba, Greece, Malaysia, Mexico, Portugal, Romania, and Turkey. It is believed that these countries, because they count on immature

12 The variables (conditions) were calibrated using two types of software, according to conditions. For the calibration of causal conditions A, C, and E, we used Stata 11.0; for conditions G, S, and P, TOSMANA was used. Different software were used for direct method calibration due to TOSMANA being perceptibly more interesting in terms of visualization and categorization of the variables according to the degree of the set of associations (OLSEN; NOMURA, 2009). The function exhibited by TOSMANA to indicate values to be calibrated helps researchers, not only because of the indication of qualitative anchors, but also since it enables the outcome according to the researchers' information and prior knowledge (OLSEN; NOMURA, 2009). For traditional qualitative anchors (and these are generally more frequently used in empirical studies: 1.0, 0.5, and 0), Stata 11.0 is perfectly adequate for direct method calibration (LONGEST; VAISEY, 2008).

TABLE 2
Outcomes of the sets of specific configurations – 1990-2010

1990		2000		2010	
Conf.	**Quantity of countries**	**Conf.**	**Quantity of countries**	**Conf.**	**Quantity of countries**
ECGSP	(6) Belgium, Canada, Finland, Japan, United Kingdom, United States	ECGSP	(3) Belgium, Canada, United States	ECGSP	(2) Canada, United States
ECgSP	(4) France, Germany, Sweden, Switzerland	ECGSp	(1) Russia	ECgSP	(7) Belgium, France, Germany, Japan, Singapore, Spain, Sweden
ECgSp	(2) Czech Republic, Spain	ECgSP	(7) France, Germany, Japan, Spain, Sweden, Switzerland, United Kingdom	ECgSp	(2) Brazil, South Korea
EcGSp	(1) Bulgaria	ECgSp	(2) Brazil, South Korea	EcGSP	(2) Finland, Norway
EcgSP	(2) Austria, Norway	EcGSp	(1) Czech Republic	EcgSP	(1) Austria
EcgSp	(4) Argentina, Brazil, South Korea, Ukraine	EcgSP	(4) Austria, Finland, Norway, Ukraine	EcgSp	(5) Bulgaria, Czech Republic, Portugal, Romania, Ukraine
eCGSP	(3) Australia, Denmark, Netherlands	EcgSp	(1) Bulgaria	eCGSP	(1) Australia
eCGSp	(2) Poland, Israel	eCGSP	(1) Australia	eCGSp	(1) Russia
eCgSP	(1) Italy	eCgSP	(3) Israel, Italy, Netherlands	eCgSP	(3) Italy, Netherlands, United Kingdom
eCgsP	(2) China, India	eCgSp	(1) Poland	eCgSp	(3) China, Poland, Turkey
ecGSP	(1) Luxembourg	eCgsP	(2) China, India	eCgsp	(1) India
ecGSp	(2) Ireland, Singapore	ecGSP	(3) Ireland, Luxembourg, Singapore	ecGSP	(1) Luxembourg
ecGsp	(1) South Africa	ecgSP	(2) Denmark, Moldova	ecgSP	(5) Denmark, Greece, Ireland, Israel, Singapore
ecgSP	(1) Moldova	ecgSp	(8) Argentina, Cuba, Greece, Malaysia, Mexico, Portugal, Romania, Turkey	ecgSp	(5) Argentina, Cuba, Malaysia, Mexico, Moldova
ecgSp	(8) Cuba, Greece, Malaysia, Mexico, Portugal, Romania, Russia, Turkey	ecgsp	(1) South Africa	ecgsp	(1) South Africa

Source: Authors' own, based on Stata 11.0 software.
Note: The indicators used in the configurations represent, respectively, the set of countries which use alternative and nuclear energy (F); exhibit scientific production (C); emit pollutant gases (G); exhibit adequate infrastructure conditions (S); exhibit economic development (P).

innovation systems, need to advance in aspects related to scientific infrastructure and strengthening of their technological capacity. All countries had shown the same configuration in the previous year (1990), revealing that the imbalance between environmental innovation and the development of structures that characterizes these countries in relation to their environmental capacity continued throughout the 1990s.

In the year 2010, the configuration (ECgSP) was the most representative among the sample countries, exhibited by seven (7) of them (which make up 17.5% of the total): Belgium, France, Germany, Japan, Spain, Sweden, and Switzerland. A “decentralization” of condition combinations among developed and developing countries was also observed. This decentralization refers, mainly, to conditions related to a higher usage of alternative and nuclear power, to an elevated scientific production, and a low level of pollutant gases. The “ideal” framework followed by the seven countries already mentioned, all of them developed, reveals that the low emission of pollutant gases came to be one of the influencing factors to environmental innovative activity. In this regard, the minimum condition of pollution is likely to foster the discovery of new environmental paradigms. In other words, when a certain high level of environmental technological activities is reached, new research in engineering and science follow suit, and, in the long-term, they converge so as to generate a bigger trend in environmental technological issues (sustainability) (WINDRUM et al., 2009).

In relation to Table 3, tests for sufficiency of possible configurations of the conditions (E, C, G, S, and P) for the desired outcome (A) are presented. Better yet, the tests exhibited on Table 3 aim to assess the results of combinations between sets of conditions and to verify whether they indeed relate to each other by means of consistency tests, according to outcome (A).[13] To Ragin (2006), the closer consistencies scores are to 1, higher the consistency is. The threshold established for consistency between the combinations and the outcome was 0.7; below this value, it would be very difficult to say whether there is any relation between the set of conditions and the outcome. With the cut-off value established between the combination of conditions, it was observed that the consistency of combination was kept close to 1, and all the solutions were statistically significant at 5%, according to the p-value. From the sets of most common conditions for each year that was analyzed, which inform the most consistent configurations for the undertaking of environmental innovative activity, the same set was reduced to a minimum number of profiles.

13 All combinations which did not have any case (observation) and combinations whose consistency value was below 0.70 were excluded from the analysis.

From the minimization of the consistency threshold and test evaluation, Table 3 shows the first, partial solutions presented by Longest and Vaisey (2008), aiming to verify common solutions and reduce them according to a logical structure based on the empirical context, i.e., which combinations of interactions between determinants led to environmental innovative activity. The sets of conditions of Table 4 represent the reduced equations of the configuration for a minimum number of sets.

TABLE 3
Minimization of the sets of conditions – 1990-2010

Year	Configurations	Raw coverage	Unique coverage	Consistency of the solution
1990	e*c*G*s*p	0.03	0.03	0.99
	e*C*G*S	0.27	0.09	0.94
	C*S*P	0.49	0.32	0.86
	Total coverage		0.61	
	Consistency of the solution		0.88	
2000	E*C*g*S*p	0.32	0.27	0.97
	e*C*G*S	0.13	0.08	0.99
	Total coverage		0.40	
	Consistency of the solution		0.97	
2010	E*c*G*S*P	0.07	0.07	1.00
	G*s*p	0.02	0.02	0.99
	Total coverage		0.08	
	Consistency of the solution		0.99	

Source: Authors' own.

The outcomes exhibit a very consistent solution for all the years, with 1990 presenting the lowest value (86%). For the same year, the partial solutions portray that high levels of CO_2 emission (G), high scientific production (C), and minimum infrastructure conditions (S) were the key factors for the greater occurrence of environmental innovations. For the year 2000, infrastructure and scientific production conditions were more conducive to the implementation of innovative environmental activity. Finally, in 2010, the gas emission condition was the most preponderant in the two partial solutions for this year, representing a large part of the sample countries.

The three sets of minimum configurations for the year 1990 and the two sets of conditions for the years 2000 and 2010 presented specific statistics regarding coverage and that, generally, are presented when there is more than one set of combination of conditions and which produce a single outcome (equifinality). Raw and unique coverage, when there are several combinations of conditions, assess the relative importance of each of the configurations. The first coverage (raw) refers to the relative empirical importance of each term in the explanation of the solution and the unique coverage depicts this empirical importance, explaining separately each term of the solution, that is, it disregards the present conditions that are covered by other solutions. Both coverages are highly significant, because they do not only reveal the coverage of each configuration, but also its relative empirical weight (RAGIN, 2006).

The outcomes exhibit a very consistent solution for all the years, with 1990 presenting the lowest value (86%). For the same year, the partial solutions portray that high levels of CO_2 emission (G), high scientific production (C), and minimum infrastructure conditions (S) were the key factors for the greater occurrence of environmental innovations. In this stage, in which the set of conditions is minimized (Table 3), only the combination of the most expressive configurations for each year is visualized, and it is not possible to determine which countries fit into their respective configurations. For the year 2000, good infrastructure and scientific production were more susceptible to the implementation of the innovative environmental activity, as indicated by the configuration with the highest consistency value (e*C*G*S).

Finally, in the year 2010, both profiles exhibited all the conditions at high levels, such as CO_2 emissions (G), infrastructure (S), usage of alternative and nuclear energy (E), and considerable level of economic development (P), with the exception of scientific activity, which showed a lower level for the implementation of innovative environmental activities. These results highlight that, for the process of accomplishing the environmental innovative activity, a large part of the countries have developed and have been moving towards a new technological paradigm, despite the differences in technological and environmental aspects between countries.

Due to the aforementioned results, it was observed that the degree of economic development was not a determinant factor in the sets of conditions. In general, what is observed from the sets was that the emission of pollutant gases and scientific production are strongly interrelated and can be characterized as strong elements associated with the occurrence of environmental innovations. In part, the results suggest that, over time, countries with a strengthened innovation structure, that is, that have good infrastructure and scientific capacity, were the most likely to carry out environmental technology activity. However, in order for the effects of environmental technologies to mitigate the negative impacts of pollution, an effort by all countries, both developed and developing, are necessary. The importance of this understanding rests on the idea that, in order to achieve a global environmental technological change, it will be necessary, beyond the conditions applied in this article, not only the introduction and the development of environmental technologies, but also the revision of social, cultural and consumption patterns.

Although the results presented (Tables 1, 2, and 3) are consistent and present sets of combinations of appropriate causal conditions, we opted to generate the QCA procedures following the criteria of Olsen and Nomura (2009). In the empirical work of the authors, a procedure was performed to analyze the consistency sensitivity and the coverage of the solution, according to the consistency threshold, considered as a parameter for the most appropriate cut-off level. For the implementation of this procedure, we used the fuzzy set and fsQCA software. The fsQCA program has, among other advantages, the possibility of investigating the Truth Table in an easier and more thorough way through several analyzes and it assists in the diversity and simplification of the final solutions (KENT, 2008).

In Table 4, the "Truth Tables" of the fuzzy sets with all combinations of the causal conditions are presented, for the timeframe of this work. At first, the Truth Tables have 32 rows (2^k(k=5)), and each of them is a combination of possible conditions. Then, after constructing the Truth Table, specifying the causal conditions and the desired outcome, one must determine the frequency threshold, especially when N (number of cases) is large (RAGIN, 2004). In this work, the minimum threshold was set with two (2) countries in each causal combination and, thus, the rows of Table 2 with a single country were eliminated.

The next step, after the construction of the Truth Table and its minimization, is the selection of the cut-off value for the consistency revealed by the causal combinations. For Ragin (2008), the cut-off value of consistency should be equal to or greater than 0.80, since lower values can be considered inconsistent. The concern about the cut-off value of consistency refers to its reflection on the consistency and the coverage of the final solution. When the cut-off level is high, the solution is consistently lower, and its coverage is lower still, generating, thus, a trade-off between the consistency and the coverage values. To support the choice as to the level of consistency, we follow the suggestion of Olsen and Nomura (2009).

TABLE 4
Truth table analysis – 1990-2010

Year	E	C	G	S	P	Frequency of cases	Consistency cutoff value	Consistency of the solution	Coverage of the solution
1990	1	0	0	1	1	2	0.99	0,95	0,95
	0	1	1	1	0	2	0.99	0.94	0,96
	0	1	1	1	1	3	0,92	0.86	0.94
	1	1	1	1	1	6	0,91	0,87	0,87
	1	1	0	1	1	4	0,90	0,80	0,89
	1	1	0	1	0	2	0,87	0,54	0,54
	0	0	1	1	0	2	0,76	0,26	0,29
2000	1	1	0	1	0	2	0.97	0.88	0.88
	0	1	0	1	1	3	0,90	0,71	0,79
	1	1	0	1	1	7	0,87	0,74	0,77
	1	1	1	1	1	3	0,83	0,77	0,77
	1	0	0	1	1	4	0,76	0,33	0,34
2010	1	0	1	1	1	2	1.00	0,98	1.00
	1	1	0	1	0	2	0,93	0,78	0,78
	0	1	0	1	0	3	0,92	0,73	0,74
	1	1	0	1	1	7	0,89	0,74	0,74
	0	1	0	1	1	3	0,87	0,57	0,62
	0	0	0	1	1	5	0,74	0.07	0.07

Source: Authors' own.

Table 4 shows that the Truth Tables in the respective years present the consistency levels on a decreasing scale and, in 2010, the lowest level of consistency found was 0.74. It is possible, then, to observe that the cut-off levels show balance between consistency and coverage of the solution. These levels for 1990, 2000, and 2010 are, respectively, 0.87, 0.83 and 0.87. The choice of these values was made based on the benchmark (0.80) and optimum (0.85) values by Ragin (2008), and they signal a consistency that is sufficient for the analysis of causal conditions. Then, the substantial difference between the consistency cut-off value and its subsequent value was verified, in addition to the values of consistency and coverage of the solution being more balanced at this point. The balance between the consistency and the coverage of the solution is relevant when the cut-off value of consistency is considered, since this balance guarantees the validation of the solution, generating, as well, empirical and theoretical significance.

Table 5, ahead, shows the countries that fit into each causal combination configured by the solutions in each year. The countries described in the relation were those which obtained a membership degree greater than 0.5 for each combination of causal conditions. The others obtained a value below 0.5, and, therefore, the results are more sensitive as regards the combination of their conditions.

TABLE 5
Countries that integrate the configurations in the intermediate solution – 1990-2010

Year	Configurations	Composition by countries
1990	S*G*C*~e	Netherlands, Australia, Poland, Denmark, Israel
	P*S*~g*E	Sweden, Norway, Switzerland, France, Germany, Austria
	S*~g*C*E	France, Sweden, Spain, Germany, Switzerland, Czech Republic
	P*S*G*C	United States, Canada, Netherlands, United Kingdom, Australia, Japan, Belgium, Denmark, Finland
	P*S*G*E	France, Canada, Sweden, Japan, Germany, Switzerland, United States, Belgium, United Kingdom, Finland
2000	P*S*~g*C	Japan, United Kingdom, Germany, France, Holland, Italy, Sweden, Switzerland, Israel, Spain
	S*~g*C*E	France, Japan, Spain, Sweden, Germany, South Korea, Switzerland, Brazil, United Kingdom
	P*S*C*E	Canada, Japan, France, Sweden, Germany, Switzerland, United States, United Kingdom, Belgium, Spain
2010	S*~g*C	Japan, United Kingdom, Germany, France, Italy, Spain, Netherlands, South Korea, Brazil, China, Switzerland, Sweden, Turkey, Belgium, Poland
	P*S*G*E	Canada, United States, Norway, Finland

Source: Authors' own.

The representation of countries exposed in Table 5 reflects various possibilities of configurations from different stages of innovation. Over the years, nations like

Canada, United States, Norway and Finland, although they have adopted strategies for the development of environmental technologies, stood out by the absence of the conditional of pollutant gas emissions for the undertaking of environmental activities. On the other hand, some developing countries are observed to have achieved various stages of configurations, combined with innovation systems of diverse features. The year 2010, for example, was a very atypical period, compared to previous years, and that may have been a reflection of the strategies adopted by some countries, such as those represented by the combination (S*~g*C)[14] and, in some ways, it represented a major step forward towards the reduction of pollutant gas emissions linked to the development of environmental innovations. Among the developed economies that presented this configuration are: Japan, the United Kingdom, Germany, France, Italy, Spain, the Netherlands, South Korea, Switzerland, Sweden, Belgium, and Poland. Among developing economies, are: Brazil, China, and Turkey (Table 5).

Again, another relevant factor verified in the results is the convergence in the minimum number of configurations of the conditions over the decades. With the possibility of identifying the countries that participated in the configuration of the conditions, it was observed that the results evolved towards new perspectives and changes and technological trajectories both by the developed countries and the developing nations, although the latter still have a timid participation in the development of innovative environmental activities. In short, the results of QCA pointed out that there was a breakthrough with regard to innovative environmental activity over the three periods examined. By this token, advances can be justified by the fact that developed countries are more present in the set of causal conditions, as well as by the insertion of developing countries: Brazil, China, and Turkey. Likewise, Lanjouw and Mody (1996) had already highlighted the good performance of developing countries such as China and Brazil for the production of environmental innovations between 1970 and 1980.

It is likely that the presence of the emission of pollutant gases will foster the creation of new markets for environmental technologies and provide incentives for countries to acquire new technologies to mitigate the negative impacts (DECHEZLEPRÊTRE et al., 2011). In the same perspective, the results QCA show that the configurations that lead to innovative environmental activity are represented by good conditions of environmental, scientific, technological, and economic capacity.

14 The meaning of the symbol ‘ ~ ‘, in Table 5, follows Ragin (2006), and it represents negation. Specifically, it negates the presence of that condition (high or low intensity), that is, when this symbol occurs there is absence of the condition to which it refers.

5. Conclusions

The development of technological innovations represents the economic progress and it is crucial to accelerate the economic growth rates of the countries. However, at present, it is necessary that economic advances are balanced between maintaining the economic growth of nations and environmental susceptibility related to impacts on the environment in the mid- and long-terms. The primary technological requirements fall on the most polluting sources, promoting and inducing the production of alternative energy technologies, recycling and waste management, energy conservation, among others. Environmental innovations, in this case, are the most efficient and able way to maintain a balance between economic growth and the search for a better quality of life.

The present work sought to incorporate elements that characterize the relationship between environmental capacity and its relation to the environmental innovations of countries, between developed and developing nations for the years 1990, 2000 and 2010. The grouping of countries and the inherent complexity when approaching national issues such as the diversity between the maturing stages of innovation systems and the catching-up processes enabled by the various stages of dynamic transformation have made this article a major challenge.

In the years 1990 and 2000, it was observed that most of the configurations of countries did not present technological environmental production as a preponderant factor contributing to the condition of CO_2 gas emissions. Only in 2010 the determinant factor of the gas emissions constituted an element for the accomplishment of environmental innovations. In this sense, this result seems to indicate that the role of regulations also presented the effect of promoting and stimulating the production of environmental technologies, at the same time in which the countries did not inhibit or slow down their process of economic growth. Developing countries such as Brazil, China, South Korea, and Turkey have achieved prominence according to the set of combinations of causal conditions similar to those of developed countries, in the years 2000 and 2010. As the results exposed in the comparative qualitative analysis show, the efforts of developing countries, especially China, in the production of environmental technologies have become increasingly relevant.

However, the participation of developed economies in the generation and dissemination of environmental technologies and the commitment to reduce environmental impacts should also be taken into consideration. Among the countries, identified by the QCA, which showed favorable conditions for technological production, France, Sweden, the United Kingdom, Germany, Spain, and the

Netherlands, in accordance with the conditions provided, were able to establish a favorable environmental technology production without high pollutant emissions being a determining factor.

From the point of view of policy suggestions, from the various Tables and stages of innovations, it is presumable that both technological and environmental policies should combine relevant actions of policy makers. An alternative that can reconcile an important research agenda with the advances found in this paper refers to the deepening of information linked to the database. In other words, from the database with the technological classification of environmental patents and variables specific to the environmental, social, and scientific context, it shall be possible to produce research that will contribute to: a) investigate the main determining factors and international agreements that promote the expansion of technological environmental activities in world economies; and b) analyze, according to the contributing factors identified, which are those that influence the most and would lead to a different dynamics in relation to the corresponding technological activities in the countries. The work and effort required in the making of article represent a step towards the development of solutions at an environmental-technological level, solutions also linked to the multidimensional nature of global environmental problems.

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Appendix

Table with descriptive information on the QCA variables (1990, 2000 e 2010)

Year	Obs	Indicators	A	E	G	S	P	C
1990	40	Average	0.0025	22.4930	7.5708	88.1125	54.9458	0.0003
		Standard deviation	0.0071	24.2965	5.2129	18.0882	166.1400	0.0003
		Minimum	0.0000	0.1208	0.7900	16.8000	1.5700	0.0000
		Maximum	0.0422	95.3932	26.2000	100.0000	972.0000	0.0011
Year	**Obs**	**Indicators**	**A**	**E**	**G**	**S**	**P**	**C**
2000	40	Average	0.0061	23.4138	8.2310	90.0125	76.5082	0.0003
		Standard deviation	0.0173	23.7294	4.6065	15.6831	191.4822	0.0003
		Minimum	0.0000	0.1269	0.9700	25.6000	1.6340	0.0000
		Maximum	0.1031	94.8449	20.2100	100.0000	955.0000	0.0012
Year	**Obs**	**Indicators**	**A**	**E**	**G**	**S**	**P**	**C**
2010	40	Average	0.0077	26.9891	8.0452	92.0350	31.6988	0.0005
		Standard deviation	0.0208	22.8432	4.4019	13.3276	24.3724	0.0004
		Minimum	0.0000	0.1951	1.3900	35.5000	1.3880	0.0001
		Maximum	0.1018	93.6006	21.6400	100.0000	102.8630	0.0012

Source: Authors' own.