The Relationship Between Environmental Technology Patenting and Environmental Performance Index in Countries: What Does It Mean and How Can We Measure It

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Abstract. National governments need to make informed decisions to ensure sustainable development and the use of new technologies. Thus, two major problems emerge: how to evaluate governments' success in encouraging companies to invest in environmental technologies, and how to measure the efficiency of technology diffusion in terms of environmental well-being. The knowledge about the relationship between environmental performance and environmental technologies at the country level enables decision-makers in the field of sustainable development to more rationally plan the costs of developing new technologies, as well as track the return on their implementation. As a result, society and industry will receive signals about the effectiveness of the implemented sustainable development policy. The main goal of the research was to overcome the gap in the field of environmental wellbeing: how to measure at the macro level the dependence of countries' success in environmental performance on how developed they are in environmental technologies. The specific objective of the study was to quantify the relationship between the integral indicator of environmental well-being Environmental Performance Index (EPI) and innovative activity in the field of environmental technology at the cross-country level. To evaluate the development of environmental technologies, the platform solution Orbit Intelligence was used, specifically, the FamPat worldwide patent database. It was confirmed that the more developed the economy, the higher EPI and the level of development of environmental technology. At the same time, no relationship was found between the 10-year change in EPI and the 10-year change in the patent activity index. The hypothesis about the statistical significance of the relationship between the integral indicators of patent activity in the field of environmental technology and the current value of EPI was confirmed. A regression dependence was determined, which was well approximated by the linear regression of EPI on the logarithm of the country's patent activity index in the field of environmental technology. The dependence can be interpreted as a slowdown in the growth of EPI when a certain level of patenting is reached. The novelty of the research lies in the fact that a framework has been proposed and implemented for assessing the relationship between environmental well-being and environmental technology. This framework can be used to study individual environmental problems in countries in more detail and to identify the level of available technologies for solving these problems.

Keywords. Environmental performance, Environmental well-being, Patent activity, Patent landscapes, Regression

1 Introduction

1.1 Problem statement

In the 21st century, the population, scientists, and leaders of many countries are aware of the importance of sustainable development and the effective solution to environmental problems, the most significant of which are global warming, a decrease in clean drinking water supplies, pollution of the world's oceans and a decrease in biodiversity. Companies need constant efforts to create innovative technologies that help neutralize the anthropogenic impact on the environment and increase the rational use of natural resources. National governments need to make informed decisions to ensure sustainable development and the use of new technologies. Thus, two major problems emerge: how to evaluate governments' successfulness in encouraging companies to invest in environmental technologies, and how to measure efficiency of technology diffusion in the terms of environmental well-being.

If we examine the relationship between environmental performance and environmental technologies at the country level, then we can identify

those countries in which the development of technology is accompanied by an increase in environmental performance and those countries that, despite the high level of technological development, have not achieved success in environmental performance. In addition, we can identify countries where technology development in companies is not sufficiently stimulated and those countries where technology is not being used effectively enough. We can also identify a trend and predict some average level of environmental performance for a fixed level of technology development and identify countries with good and bad practices in the use of technologies. This knowledge will enable decision-makers in the field of sustainable development to more rationally plan the costs of developing new technologies, as well as track the return on their implementation at the macro level. As a result, society and industry will receive signals about the effectiveness of the implemented sustainable development policy. Today, the importance of data-driven insights to improve environmental decision-making and ensure a sustainable future is widely recognized. For countries to make evidence-based sustainable development decisions based on data, it is necessary to assess the current state of environmental performance and existing resources that can improve this state.

Environmental technologies are a key resource that provides environmental well-being. The significance of these technologies lies, firstly, in the fact that they are a sharable resource. Second, an environmental technology can be seen as a resource that enhances the efficiency of other resources. Overall, there is a research gap in the field of environmental well-being: how to measure at the macro level the dependence of countries' success in environmental performance on how developed they are in environmental technologies.

1.2 Current solution

The Environmental Performance Index (EPI), based on 40 environmental indicators, is widely used to assess the effectiveness of countries' environmental policies [1]. These indicators are grouped into three groups with corresponding sub-indices: Climate Change, Environmental Health, Ecosystem Vitality. Each of these sub-indices consists of individual components, which in turn are calculated based on the transformed values of statistical indicators of the country's ecological state. Each sub-index is calculated as a linear convolution of its constituent components with different weights [1]. The Climate Change sub-index is represented by one component, Climate Change Mitigation. The Environmental Health sub-index consists of components: Air Quality, Sanitation & Drinking Water, Heavy Metals, Waste Management. The Ecosystem Vitality sub-index includes components: Biodiversity & Habitat, Ecosystem Services, Fisheries, Acid Rain, Agriculture, Water Resources.

The individual components make it possible to assess the effectiveness of countries in mitigating the consequences of climate change, increasing the viability of ecosystems, and protecting the environment. The composition of these individual components allows us to say that with the help of EPI, we indirectly measure not only environmental performance but also environmental well-being. The integrated indicator EPI makes it possible to identify leaders and outsiders in the field of sustainable development. EPI-2022 shows the progress countries have made in sustainable development. For 180 observed countries, the value of the integrated EPI index is on average higher for countries with a higher level of development in terms of GDP per capita: "EPI scores are correlated with country wealth" [1]. It should be noted that this regression dependence is linear on the logarithm of GDP per capita [1]. The study [2] offers a quantitative description of the relationship between globalization and environmental indicators that are part of the EPI. Panel data for 148 countries from 2001 to 2018 confirmed that social and political globalization contributes to the improvement of environmental performance, while economic globalization has no impact on environmental performance.

Social studies of the influence of the environmental concern of the population of various countries upon the level of economic development often demonstrate polar points of view: from the denial of such dependence to the confirmation of its existence with a positive or negative sign [3]. In the study [3], conducted using panel data for 82 countries over seven years, the following variables were identified as predictors of environmental concern: exposure to environmental degradation (positive relationship), economic abundance (negative relationship). The volume of exports as a percentage of GDP has a negative impact on concern, and the percentage of exports to highly developed countries has a positive effect.

We have proved [4] that data on search queries on the Internet for keywords related to environmental pollution reflect the degree of public concern about the environmental situation in a region and can be used as an indirect indicator of environmental trouble. On an intuitive level, one can assume that there is a relationship between the success of countries in achieving sustainable development goals and the development of technologies to achieve these goals.

Patent analytics methods have been developed to analyze technological trends and the level of technology development, including trends in the field of sustainable development. Scientific research in this area is usually aimed at evaluating the development of certain groups of technologies and identifying technological trends in eco-innovations [5,6].

In [7,8] the impact of patent activity on environmental indicators was estimated. In the study [7], on the example of Spain, a statistically significant negative impact of patent activity in the field of environmental technologies on the volume of CO_2 Emissions was confirmed: as all factors held constant, an increase in environmental technology patents leads to a decrease in carbon emissions. The findings of the study [8] show that the number of patent applications in the field of environmental technologies is an important predictor of the ecological footprint in the United States,

causing a decrease in environmental deprivation in the long term. These results show that the use of technological innovations in the field of ecology can contribute to the sustainable development of countries.

1.3 Proposed solution

Since the level of environmental well-being can be representatively assessed using the EPI index, we, firstly, were faced with the task of identifying the main trends in the development of environmental technologies at the macro level. Secondly, we were faced with the task of determining at the macro level for a sample of countries' regression dependencies, in which the indicator of technology development is an independent variable, and the integral indicator of environmental wellbeing is a dependent variable. Additionally, regressions may be evaluated for the change of these indicators over some period. As a quantitative characteristic of environmental well-being, we used an integral indicator of the ecological state, the Environmental Performance Index (EPI) [1].

Patenting indicators for the technological area "Environmental technologies" were used as characteristics of technology availability for sustainable development. There are several reasons for the choice of these indicators:

- the traditional use of the characteristics of patenting as the results of the effectiveness of research and development;
- the possibility of interpreting indicators as characteristics of shared resources;
- openness and reliability of patent data;
- the ability to fine-tune queries to patent databases.

At the same time, it is difficult to talk about clear causal relationships between patenting and the level of environmental well-being. However, such an analysis makes it possible to clarify the mutual influence of technological development and the ecological state.

1.4 Research novelty and objective

Overall, the main goal is to overcome the research gap in the field of environmental well-being: how to measure at the macro level the dependence of countries' success in environmental performance on how developed they are in environmental technologies.

The specific objective of the study was to quantify the relationship between the integral indicator of environmental well-being Environmental Performance Index and innovative activity in the field of environmental technology at the cross-country level, as well as between the growth of these indicators over a 10-year period. To achieve this goal, we have formed a sample of countries that are currently the most active in patenting solutions in the field of environmental technologies. To form the sample, we used the patent database and analytical tools of platform solutions Orbit Intelligence [9]. For the same countries, the EPI values were taken from the report for 2022 [1]. Next, we used correlation and regression analysis of the obtained data. As a result, we confirmed the hypothesis about the statistical significance of the relationship between the value of the Environmental Performance Index and the indicator of patent activity in the field of environmental technology. A linear regression of the Environmental Performance Index from the logarithm of the country's patent activity index in the field of environmental technology was determined. This can be interpreted as a slowdown in the growth of the Environmental Performance Index when a certain level of patenting is reached. In addition, it was confirmed that the more developed the economy, the higher its Environmental Performance Index and the higher the level of development of environmental technology. We failed to establish the relationship between the 10-year change in the Environmental Performance Index and the 10-year change in the patent activity index.

2 Materials and Methods

The methodology for constructing the Environmental Performance Index based on statistical indicators of the ecological state of countries has been developed over the past two decades and was presented in the report [1]. We used country summary data on EPI score for 2022 and EPI 10-year change presented in [1].

To assess the level of development of environmental technologies, one of the leading platform solutions Orbit Intelligence [9] was used, specifically, the FamPat worldwide patent database and software for patent research and analysis. The data sources for FamPat include 110 patent-issuing authorities with up to date 66 million patent families.

The time depth of the search was from 2003 to 2023. The unit of observation was a patent family, i.e. all patents describing one invention. Only data on valid patents and pending applications were analyzed. The geographical scope of patenting was not limited.

The visualization tools QUESTEL - ORBIT were used to build diagrams. Some of the diagrams were built by the authors using analytical data obtained from the QUESTEL-ORBIT system.

We analyzed data on submitted applications and registered patents for the technology domain "Environmental technology". The selection of technological areas available only in Orbit Intelligence [8, 9] was used as groups of classes and subclasses of the International Patent Classification (IPC). In total, 35 technological domains are distinguished, which are combined into groups: Chemistry, Electrical Engineering, Instruments, Mechanical Engineering, and Others. The technological area investigated in the work is part of the Chemistry group.

We used the queries as, for example, (("ENVIRONMENTAL TECHNOLOGY")/TECT AND (EPD < 2023-01-01) AND (STATE/ACT=ALIVE)) or (("ENVIRONMENTAL TECHNOLOGY")/TECT AND (EPD < 2013-01-01) AND (STATE/ACT=ALIVE)).

Similar patterns can probably be obtained using other patent databases, such as those of the World Intellectual Property Organization, the European Patent Office,

Goggle, national patent offices and others, using International Patent Classification codes and corresponding keywords. Note that the classification into technological domains is unique for Orbit Intelligence [8, 9].

Promising areas of research in the analyzed technological area were determined by:

- by the ratio of active patents and applications under consideration (Technology domain "Environmental technology", Status Alive, Granted / Pending);
- by year-to-year growth in the number of pending applications.

The dynamics of patent activity, which also indicates interest in the technological field and its prospects, was estimated by the number of patent families in the 1st year of filing an application. In addition, an analysis was made of the distribution of patent families in the technological field by the main concepts and by related technological fields, which are most often found in patents.

World leaders in the analyzed technological field were determined by the number of active patent families published in the country's patent office. Expansion into markets indicating the demand for technology, was estimated by the number of active patent families from right holders in various patent offices of countries. The prevalence of technology, that is, the expansion of world leaders in subject areas, was estimated by the number of active patent families from right holders by application area.

To identify the mutual influence of Environmental technology on EPI, the distribution of existing patent families for the technological area "Environmental technology" was analyzed by countries of protection (countries in which inventions are protected by a patent). The top 30 patent offices of countries have been identified. The European Patent Office (EP), the patent office of the World Intellectual Property Organization (WO), as well as patent offices of European countries, were excluded from the list, since many patent holders in these countries, do not register applications directed to the European Patent Office (EP) and the Patent Office of the World Intellectual Property Organization (WO) in national patent offices. For selected countries, an index of patent activity in the field of "Environmental technology" was proposed and determined as the ratio of the number of active patent families in this field to the volume of GDP, expressed in US dollars at purchasing power parity. A similar normalization of the total number of patent families is used in the methodology for constructing the components of the global innovation index [10].

Next, a pairwise regression was built and analyzed between the values of EPI and the index of patent activity in the technological area "Environmental technology". We used the logarithmic transformation of the independent variable. To assess the statistical significance of the regression dependence, p-values were calculated to test the hypotheses of non-zero regression coefficients. In addition, the relationship between the growth values of these indicators over a 10-year period was considered.

3 Results and discussion

3.1 Prospects for the development of environmental technology

The ratio of patent applications under consideration and approved applications characterizes the intensity of patenting. The intensity of patenting in the technological field indirectly characterizes the development prospects and the demand for new technologies in this field by the economy and society. To understand the data in Table 1, the following features of application counting should be considered. Not individual patent applications are counted, but patent families. Each active patent family (Alive) can be represented by both pending applications and already approved applications. The family with the status "approved" necessarily includes approved applications. There are no approved applications in families with the status “pending”.

Table 1. The ratio of filed and approved patent applications (only valid patents in the technological field "Environmental technology", built according to [9]), the number of patent families.

Legal status	Before 01.01.2023	Before 01.01.2013
Alive	1 046 707 (100%)	71 083 (100%)
Granted	860 942 (82%)	67 445 (95%)
Pending	185 765 (18%)	3638 (5%)

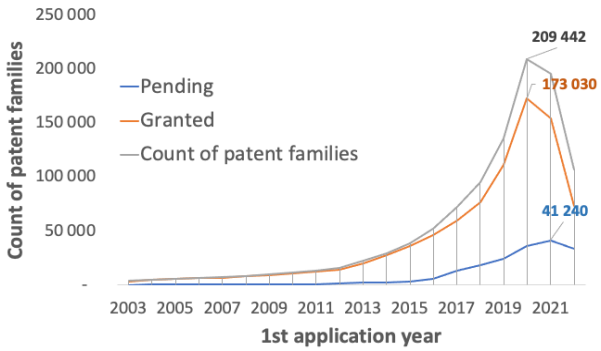

Fig. 1. Dynamics of patent activity for technological area "Environmental technology": the distribution of the number of patent families for the 1st application year, according to [9].

We compared the number of patent families for the technological area "Environmental technology" at two points in time, separated by 10 years. There is a significant increase in the number of active patents, as well as an increase in the share of pending applications. An analysis of the ratio of patent families under consideration and patent families with applications approved by 2013 and by 2023 showed that the proportion of patent families under consideration has increased. This happened because of a combination of two factors - the increase in patent activity and the increase in time for consideration of applications. When analyzing the dynamics of patent activity in the technological field "Environmental technology", the data

were grouped by the year of filing the first application in the patent family (Figure 1). The reduction in patent families in 2021 and 2022 is explained by the fact that not all applications are included in the database yet.

3.2 Concepts and related areas for the Environmental technology area

To determine the main concepts used in the patent families of the technological field "Environmental technology", the Questel Orbit service was used, which makes it possible to build clusters of jointly used keywords that are interconnected in meaning (Figure 2). The concept represents the theme that characterizes the cluster. Some concepts are most common, for example - Water Inlet, Air Outlet, and Purification.

Another Questel-Orbit service made it possible to determine the number of patent families that simultaneously belong to the "Environmental technology" technology area and the remaining 34 patent areas (Figure 3).

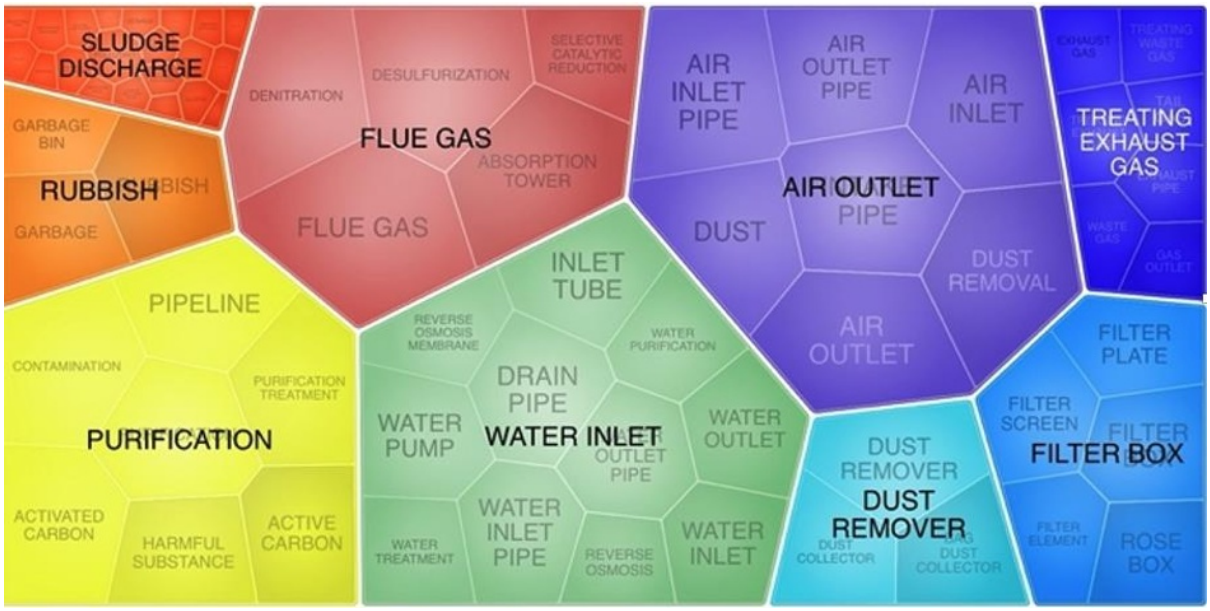

Fig. 2. Basic concepts for the technological area "Environmental technology": the distribution of patent families of the technological area "Environmental technology" by thematic areas most often found in patents, built according to [9].

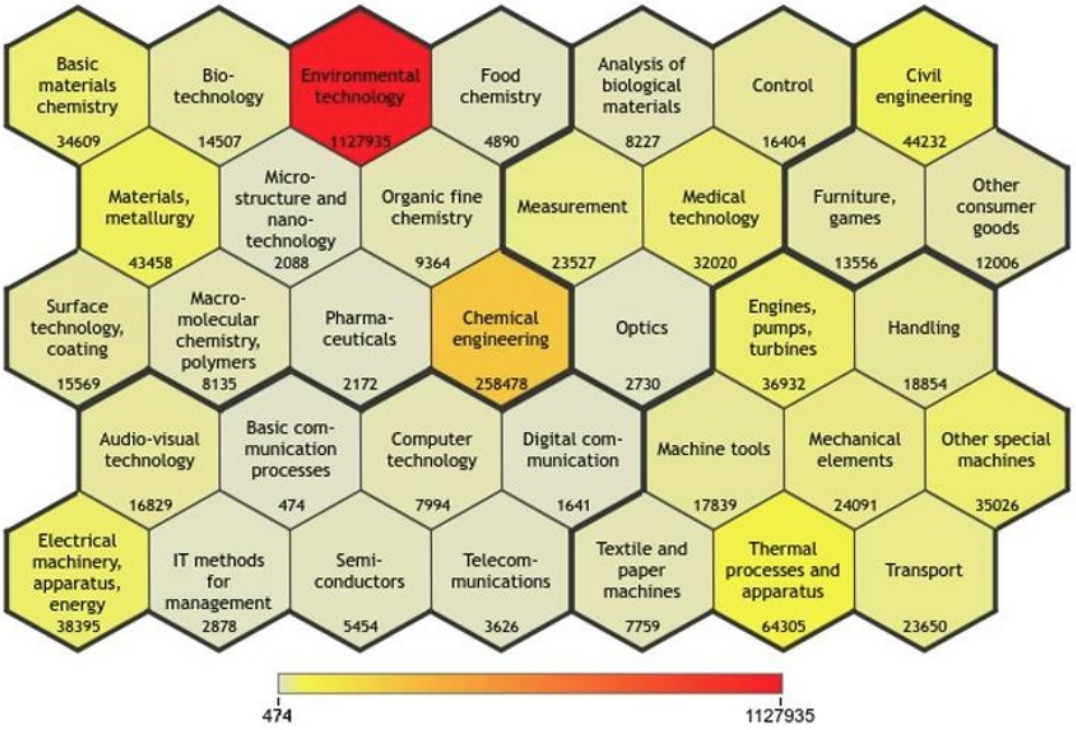

Fig. 3. Related technological areas for patent families from the technological area "Environmental technology", built according to [9], the number of active patent families, before 2023.

3.3 Leading countries and companies for the environmental technology area

In total, as of January 1, 2023, 1,046,707 valid patents in this area have been identified. China is a leader as a patent publishing country. The Chinese office accumulates 89% of patents, the US, and Japan 7% each, and Korea 6%. At WIPO and European Patent Offices 1% and 4% respectively. It should be noted that the total number of patents for the top 20 countries across all patent offices is 1.32 times greater than the total number of patents, since some patents are registered simultaneously in several patent offices (Figure 4).

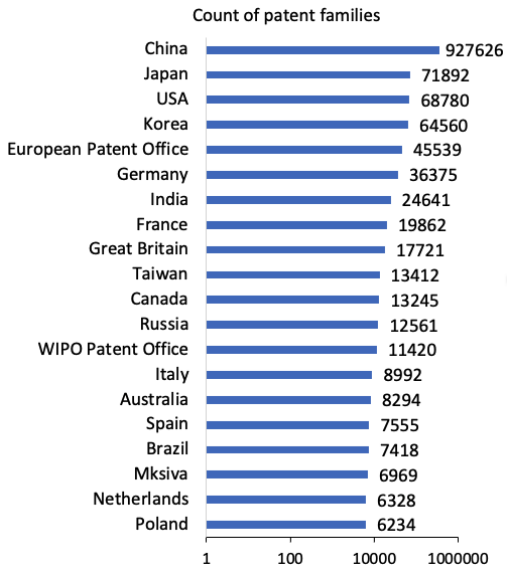

Fig. 4. World leaders (top 20) in terms of the number of active patent families published in the country's patent office for the technological field "Environmental technology", built according to [9].

It is widely known that China is the world leader in the total number of patents. At the same time, one must consider that China publishes fewer patents in other countries than other countries do in the China patent office (Figure 5). This indicates the importance of the Chinese market for the global economy.

	CN	JP	US	KR	EP	DE	IN	FR	GB	CA
CHINA PETROLEUM & CHEMIC	4340	31	60	24	44	9	27	7	6	14
TOYOTA MOTOR	995	2526	1314	198	598	799	272	390	288	24
GREE ELECTRIC APPLIANCES	1929	3	10	1	17	4	5	3	4	0
SINOPEC	1846	1	9	1	8	2	2	0	1	1
TSINGHUA UNIVERSITY	1644	31	114	9	45	33	6	20	33	6
TPRI	1648	4	0	0	0	0	0	0	0	0
MIDEA GROUP	1578	12	39	11	42	15	9	5	8	6
HYUNDAI MOTOR	373	74	546	1426	42	355	17	32	29	2
BEIJING UNIVERSITY OF TECHN	1411	0	23	0	16	0	0	0	0	0
WEICHAI POWER	1229	0	10	0	18	4	4	3	3	2

Fig. 5. Market Expansion: Distribution rights holders by offices of countries for filing applications and registering patents for the technological field "IT "Environmental technology", built according to [9].

3.4 Relationship between Environmental technology patents and Environmental Performance Index

When forming a sample of countries to identify dependence, we excluded European countries from the top 30 leading countries that are under the jurisdiction of the European Patent Office (EP). Also excluded are data on the number of patent families, registered with the patent office of the World Intellectual Property Organization (WO).

Figure 6 illustrates the validity of our hypothesis about the possibility of quantitative confirmation of the relationship between the EPI score and patent activity in the technological field "Environmental technology". We have identified a statistically significant regression dependence for a group of 11 countries that are in the top countries in terms of the number of active patent families published in the country's patent office in the technological field "Environmental technology".

We found a similar logarithmic dependence on the index of patent activity of countries for the integral indicator of intellectual capital [11]. Thus, we can suggest that technologies are not only a resource for sustainable development, but also for the development of intellectual capital and the knowledge economy.

A study on patent data on water conservation and supply technologies [12] showed that even those technologies that are more needed in underdeveloped countries are being more actively used in highly developed countries. Therefore, the dissemination of technologies as a shared resource to less developed countries that need these technologies is of great social, economic and environmental importance.

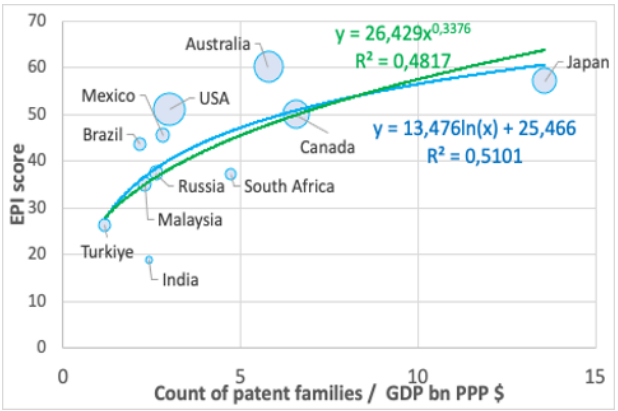

Fig. 6. Positive relationship between EPI score and patent activity in the technological area "Environmental technology". The size of the bubble is proportional to GDP per capita in US dollars, plotted according to [1, 9].

A power regression was added to illustrate some similarities of our results to those obtained in [13]. In [13] patenting was considered as an activity resulting in new innovative products rather than an output of R&D. Linear regressions linked the log number of new innovative products belonging to firms and product categories to the log number of patent applications filled

in some previous year. For all regressions obtained in [12], the value of the power parameter is <0.1, which means that there is a noticeable slowdown in the growth of the dependent variable with an increase in the independent variable characterizing patent activity.

Logarithmic regression:

$$y = 13{,}476\ ln(x) + 25{,}466;\ R^2 = 0{,}5101, \quad (1)$$

where y is EPI score,

x is a patent activity index, count of patent families / GDP bn PPP $.

Logarithmic regression gives the correct interpretation for the coefficient of determination as a proportion of the explained variance of the dependent variable.

Power regression:

$$y = 26{,}429\ x^{0{,}3376};\ R^2 = 0{,}4817, \quad (2)$$

where y is EPI score,

x is count of patent families / GDP bn PPP $.

The power regression is like that obtained in [13]. The value of the exponent at x can be interpreted as the elasticity of the EPI score with respect to the patent activity index. Elasticity is calculated as the relative change in the dependent variable per unit relative change in the independent variable. In other words, with an increase in the patent activity index by 10 times, the EPI score will change by 10 * 0.3376 = 3.376 times.

The more developed the economy (GDP per capita in US dollars), the higher the level of EPI score and the higher the level of development of environmental technology. The regression line in figure 6 illustrates this rather predictable relationship. However, for China and the Republic of Korea, this dependence is not fair. The reason for this may be that these countries show much more patent activity than the rest of the top countries. For the Republic of Korea, the patent activity indicator is 27 (Count of patent families / GDP bn PPP $), and for China, it is equal to 34.

At the same time, we were unable to identify cross-country patterns between the 10-year change in the patent activity indicator and the 10-year change in EPI score (Figure 7).

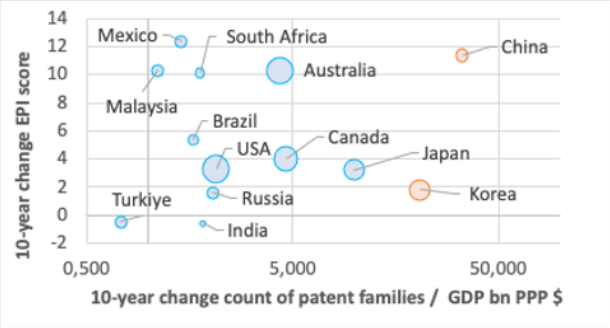

Fig. 7. 10-year change EPI score and 10-year change count of patent families / GDP bn PPP $ in the Environmental technology area. The size of the bubble is proportional to GDP per capita in US dollars, plotted according to [1, 9].

This fact may evidence a significant time lag between the moment a technology is patented and its widespread use, which contributes to sustainable development and is reflected in statistical indicators. Currently the greatest achievements in sustainable development, driven using innovative environmental technologies, have countries that are consistently focused on innovation in the field of environmental technology. Countries such as China and Korea will see a return on patent activity after a certain period.

4 Conclusion

The relationship between the integral indicator of environmental well-being (Environmental Performance Index) and innovative activity in the field of environmental technology at the cross-country level was studied.

The hypothesis about the statistical significance of the relationship between the integral indicators of patent activity in the field of environmental technology and the current value of the Environmental Performance Index was confirmed. A regression dependence was determined, which was well approximated by the linear regression of the Environmental Performance Index on the logarithm of the country's patent activity index in the field of environmental technology and with the power dependence. Regressions can be interpreted as growth retardation of the Environmental Performance Index upon reaching a certain level of patenting in environmental technology.

It was confirmed that the more developed the economy, the higher the Environmental Performance Index and the higher the level of development of environmental technology. At the same time, no relationship was found between the 10-year change in the Environmental Performance Index and the 10-year change in the patent activity index.

This study contains useful methodological recommendations. The novelty of the research lies in the fact that a framework has been proposed and implemented for assessing the relationship between environmental well-being and environmental technology. This framework can be used to study individual environmental problems in countries in more detail and to identify the level technology availability for solving these problems. For such purposes, it is promising to refine the index of patent activity by IPC (International Patent Classification) codes for technological domain environmental technology and identify its statistically significant impact on individual components of the Environmental Performance Index. The main value of the study is that the proposed framework can be used to enable policymakers to make evidence-based decisions in the field of sustainable development based on data on the current state of environmental performance and existing technologies that can improve this state.

This study contains several generalizations about the relationship between patent activity and environmental well-being, although there are some limitations. As a quantitative indicator of environmental well-being, we used the EPI score, as an integral indicator, thus, it does not allow us to measure which of the environmental

problems is more acute for the country. Therefore, when using the proposed framework for assessing the ecological state of a country caused by the most acute problems and its relationship with the level of technology development, it is necessary to use EPI components that are more sensitive to the analyzed problem instead of the EPI score. The approach used to evaluate patent activity assumed a selection of patents for the technological domain "Environmental technology", the formation of which by IPC codes and keywords is the know-how of Questel, which provides Orbit Intelligence platform solutions [9]. We used the FAMPAT patent database. When using other patent databases, the composition of patent families may be different.

Acknowledgements

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