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SUSTAINABLE DEVELOPMENT IN THE CONTEXT OF INNOVATION OF SELECTED COUNTRIES IN 2017-2021

Abstract

The aim of this article is to identify and quantify the relationship between innovation measures and predictors of sustainable development in selected countries. Public statistics resources were used as the source of data collection. The research period includes 6 time intervals, covering the years 2016-2021. The objects of the research turned out to be Poland, the United States, China, Japan and the EPO. The collected data were compiled using basic descriptive statistics. Several measures were identified and defined in an arbitrary manner, allowing research to be carried out and conclusions to be drawn. The results of the analysis were presented in tabular, graphical and descriptive form. The nature of the considerations is overwhelmingly empirical. The practical implication of the study may be the fact of indicating the strength of the relationship connecting selected innovation measures with energy consumption (measured by CO2 emissions per capita).

Keywords: innovation, sustainable development, R&D activities, patents, trademarks, CO2 emissions per capita.

JEL Classification: O32, O57, Q56

Paper type: Theoretical research article

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Introduction

Modern societies face complex challenges that require well-thought-out development strategies. In this context, the concept of sustainable development has emerged as not only a necessity, but also an important driver of innovation. Sustainability and innovation are the two closely linked concepts. Sustainable practices require finding new, environmentally friendly solutions, which drives innovation in various sectors such as energy, transport and agriculture. Sustainability encourages the development and adoption of green technologies i.e. the technologies that aim to reduce the environmental impact of various industries, supporting innovation in clean energy, waste reduction and environmentally friendly products.

The paper analyzes the relationship between sustainable development and the innovation process, pointing out the interdependence of these two aspects. In it there will be presented a couple of examples of how a sustainability-based approach stimulates creative thinking and leads to the development of solutions with greater transformative potential. By analyzing this complex relationship, the paper aims to highlight that the pursuit of sustainable development not only contributes to solving global problems, but also constitutes an important stimulus for creativity and technological progress, driving innovation in various fields. The aim of these considerations was to identify and quantify the relationship between innovation measures and predictors of sustainable development in selected countries.

The research problem: *Analysis of the impact of determinants of innovative activity on energy consumption per person in selected countries.*

The research questions:

1. Is there a relationship between the effectiveness of patents and CO_2 emissions per capita?
2. Is there a relationship between trademark effectiveness and CO_2 emissions per capita?
3. Do R&D expenditures affect the consumption of energy from renewable sources per capita, and to what extent?

The research hypotheses:

1. There is a relationship between the success rate in obtaining patents and CO_2 emissions per capita. As the effectiveness of patents increases, CO_2 emissions per capita decrease.
2. There is a relationship between the effectiveness of activities related to applying for a trademark and CO_2 emissions per capita.
3. Expenditures on research and development activities have a moderate impact on the consumption of energy from renewable sources.

1. Sustainable development in the context of innovation in the light of literature studies

In 2015, the UN endorsed the 2030 Agenda and the Sustainable Development Goals, a globally accepted pathway to achieving sustainable development in which science, technology and innovation are key drivers for the positive transformation of economies (Gil, 2017).

Moreover, sustainable development is now a competitive advantage for organizations. As observed by Velázquez-Álvarez& Vargas-Hernández (2012), they increase their social and environmental impact through innovative, cost-effective, durable, reparable, reusable, recyclable and biodegradable products and materials. Incorporating sustainability into a company's strategy is fundamental to success. Science and technology research help identify application segments of sustainability innovation systems, mainly covering industry.

Kanda *et al.* (2020) observe that innovation can have an adverse impact on sustainability, which is why ecological systems are crucial to connecting social systems with the environment. In some other paper Weitz*et al.* (2018) hold a stance that sustainable development innovations aligned with the 2030 Agenda guide governments, businesses and academia to integrate the economic, social and environmental dimensions.

2. Data analysis of selected innovation measures for Poland, the EU, China, Japan and the United States in 2017-2021

This part of the paper is devoted to a detailed analysis of key innovation indicators, which constitute an important pillar in assessing the dynamics of economic development. In the light of accelerating technological changes and market competitiveness, submitted patents and obtained trademarks constitute a measure of the innovative activity of enterprises. By analyzing them, it is possible to show trends and identify countries with the highest creative potential. Additionally, R&D spending data sheds light on the private and public sectors' commitment to creative progress.

The first analyzed measure concerns the number of patent applications. The data are presented in **Table1.**

Table 1. Number of patent applications in 2017-2021

	2017	2018	2019	2020	2021	Mean	Dynamics of changes between 2017-2021
Poland	4041	4322	3999	4098	3488	3989.6	-13.7%
EPO	166585	174397	181479	180346	188778	178317	13.3%
United States	606956	597141	621453	597172	591473	602839	-2.6%
China	1381594	1542002	1400661	1497159	1585663	1481415.8	14.8%
Japan	318479	313567	307969	288472	289200	303537.4	-9.2%

Source: Own elaboration after: https://www.wipo.int; [accessed: 25.08.2023]

Between 2017 and 2021, Poland saw a downward trend in patent applications, with the average number of patents filed being approximately 3,990 per year.This period was characterized by a significant decline of 13.7% compared to 2017. At the same time, the European Patent Office (EPO) experienced a marked increase, with an annual increase in patent applications of 13.3%.The United States recorded a slight decline of 2.6%, reaching an average number of reports of 602,839. In this context, China showed the most dynamic change, with an increasing trend of an impressive 14.8% on an annual average, which translated into an average number of reports of approximately 1,481,416. In contrast, Japan experienced a decline of 9.2% over the period, with an average number of reports of 303,537 per year. Another issue that was analyzed was the effectiveness of activities related to obtaining a patent.The relevant data are presented in **Table 2**.

Table 2. Effectiveness of activities related to obtaining a patent

	2017	2018	2019	2020	2021	Mean	Dynamics of changes between 2017-2021
Polska	71.9%	68.9%	76.1%	56.3%	95.2%	73.7%	32.4%
EPO	63.4%	73.2%	75.9%	74.1%	57.6%	68.9%	-9.1%
United States	52.5%	51.5%	5.7%	58.9%	55.3%	44.8%	5.3%
China	30.4%	28.0%	32.3%	35.4%	43.9%	34.0%	44.3%
Japan	62.7%	62.0%	5.8%	62.2%	63.8%	51.3%	1.7%

Source: Own elaboration based on publicly available data

In the case of Poland, the success rate in obtaining patents showed some irregularity, reaching its lowest level in 2020 (56.3%) and increasing significantly to 95.2% in 2021. The dynamics of changes between 2017 and 2021 reached 32.4%, which indicates a clear improvement in the efficiency of obtaining patents. When compared to other countries,

Poland presented a higher level of change dynamics than most of them. The European Patent Office (EPO) saw its success rate decline by 9.1% over the same period. As for the other selected countries, the United States shows a slight increase of 5.3%, China shows an impressive increase of 44.3% and Japan a minimal change of 1.7%.

The forecast of patent effectiveness indicator until 2025 was also examined. In the years 2023-2025, Poland is expected to have a constant increase in patent efficiency, reaching 77.72%, 66.50% and 78.66% of obtained patents, respectively. These results show that Poland may experience some variability, but the overall trend indicates a moderate increase in effectiveness in the context of patent activity. In the case of the European Union, patent effectiveness in the analyzed period was 60.62%, 58.99% and 57.37%, respectively. The downward trend indicates some difficulty in effectively converting patent applications into full-fledged patents. This may be due to such obstacles as increasing competition, the complexity of the patenting process and other regulatory factors.

When analyzing the issue of innovation, the number of trademark applications was also checked. The **relevant** data are presented in **Table 3.**

Table 3. Number of trademark applications in 2017-2021

	2017	**2018**	**2019**	**2020**	**2021**	**Mean**	**Dynamics of changes bewteem 2017-2021**
Poland	40434	38905	38781	37629	42755	39700.8	5.7%
European Union Intellectual Property Office	371508	392925	407712	438511	497542	421639.6	33.9%
United States	613921	640181	672681	870306	899678	739353.4	46.5%
China	5739823	7365522	7833081	9345757	9454794	7947795.4	64.7%
Japan	560269	512156	546244	421166	364376	480842.2	-35.0%

Source: Own elaboration after: https://www.wipo.int; [accessed: 25.08.2023]

In Poland, the number of reports fluctuated around 39,700.8 per year, and the dynamics of changes between 2017 and 2021 was 5.7%. As for Europe, the European Union Intellectual Property Office (EUIPO) has seen significant growth, with an average number of submissions of 421,639.6. This means a growth dynamics of 33.9%, which may suggest the increasing importance of trademark protection.

In the United States and China, there is a dynamic increase in the number of trademark applications. The United States has an average number of reports of 739,353.4, i.e. an increase of 46.5% over the period analyzed.

In China, the number of reports reached an impressive 7,947,795.4 per year, which resulted in a dynamic increase of 64.7%.This may be the result of the growing importance of the Chinese market and the global nature of the activities of companies from this country. In contrast, Japan showed a decline in the number of trademark applications, with a value of 480,842.2 per year. The rate of change in Japan was -35.0%, which may reflect differences in business strategies, market interest or other factors affecting the need for trademark protection. The analyzed data show a varied picture of the number of trademark applications in the surveyed countries. EUIPO, the United States and China show clear increases, while Poland and Japan show stability or decline in this respect.

As in the case of patents, the effectiveness of trademark application activities was measured. The data are presented in **Table 4.**

Table 4. Effectiveness of activities related to obtaining a trademark

	2017	2018	2019	2020	2021	Mean	Dynamics of changes between 2017-2021
Poland	95.1%	88.6%	83.7%	59.7%	90.3%	83.5%	-5.1%
European Union Intellectual Property Office	90.3%	87.9%	89.0%	87.8%	91.6%	89.3%	1.4%
United States	58.9%	60.1%	65.3%	46.0%	54.6%	48.7%	-7.4%
China	49.1%	67.8%	81.8%	61.8%	82.1%	68.5%	67.3%

Source: Own elaboration based on publicly available data

In Poland, the dynamics of changes between 2017 and 2021 was a negative one (-5.1%), which suggests a decrease in the effectiveness of the process of obtaining trademark protection. In 2021, the percentage of obtained marks was 90.3%, which means an improvement compared to the previous year (59.7%), but in the next five years a slight weakening of effectiveness may be observed. The European Union Intellectual Property Office (EUIPO) maintained a relatively stable level of efficiency, oscillating around the average value for the analyzed period, i.e. 89.3%. This is an expression of a relatively equal approach to the process of obtaining trademark protection.

As in the case of patent effectiveness, the indicator's forecast until 2025 was also checked. In the case of Poland, the forecast indicates a decline in this indicator in the following years, reaching approximately 40-45% in 2023-2025. This suggests that the trademark registration process in Poland is becoming more competitive and demanding. In the case of the European Union, the forecast is more optimistic. After an initial period

of stability, EU efficiency shows an upward trend, reaching a level of approximately 91-92% in 2023-2025. This could mean that the trademark registration process becomes more efficient, which is beneficial for companies operating in the EU.

The last issue regarding innovation measures covers both research and development expenditure in 2017-2021 in the analyzed countries. The relevant data are presented in **Table 5**.

Table 5. Expenditures on research and development (% of GDP)

	2017	2018	2019	2020	2021	Mean	Dynamics of changes between 2017-2021
Poland	1.03	1.21	1.32	1.39	1.44	1.278	39.8%
UE-27	2.03	2.07	2.11	2.19	2.15	2.11	5.9%
United States	2.9	3.01	3.17	3.47	3.46	3.202	19.3%
China	2.12	2.14	2.24	2.41	2.44	2.27	15.1%
Japan	3.17	3.22	3.22	3.27	3.3	3.236	4.1%

Source: Own elaboration after: https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm; [accessed 26.08.2023] and http://www.stats.gov.cn/english/PressRelease/202201/t20220127_1827065.html; [Accessed: 26.08.2023]

The presented data on research and development expenditure (in relation to % of GDP) in 2017-2021 show the involvement of individual countries in developing innovative activities, reflecting their ability to invest in the future, technological development and strengthening competitiveness. Poland has recorded dynamic growth in research and development spending, with an increase of 39.8% between 2017 and 2021.The rate of expenditure in relation to GDP increased from 1.03% in 2017 to 1.44% in 2021.This suggests a desire to increase innovation and technological progress. At the European Union level, the R&D expenditure rate represented a stable average level of 2.11% of GDP over the period considered. The gradual growth between 2017 and 2021 (by 5.9%) demonstrates the commitment to developing a competitive economy based on innovation.

It was also examined what the forecast ratio of R&D expenditure in the context of GDP in 2025 will look like in the analyzed countries.

A gradual increase in research and development expenditure is expected in Poland (from 1.66% of GDP in 2023 to 1.85% of GDP in 2025), whatnot only indicates an increased commitment to innovation, but could also herald an impact of the country's long-term competitiveness.In the European Union, stable research and development expenditure is forecasted at the level of approximately 2.28% of GDP in 2023 and slightly higher (2.37% of GDP)

in 2025.Despite this stability, there is potential to increase spending to support economic growth.

3. CO_2 emissions and the use of renewable energy sources as issues affecting sustainable development

This part will analyze two important issues that play an extremely important role in the face of contemporary ecological and energy challenges - carbon dioxide (CO_2) emissions and the role of renewable energy. First, it was examined what CO_2 emissions per capita were in the surveyed countries. The relevant data are presented in **Table 6**.

Table 6. CO_2 emissions in the years 2017-2021 (in tones per capita)

	2017	2018	2019	2020	2021	Mean	Dynamics of changes between2017-2021
Poland	9	9	8	8	9	8,.6	0.0%
UE-27	8	8	8	8	8	8	0.0%
United States	16	16	16	14	15	15.4	-6.3%
China	7	7	8	8	8	7.6	14.3%
Japan	9	9	9	8	9	8.8	0.0%

Source: Own elaboration after https://ourworldindata.org/co2; [accessed: 27.08.2023]

The data on carbon dioxide (CO_2) emissions in 2017-2021 presented in **Table 6** show the degree of involvement of individual countries in reducing greenhouse gas emissions, which is an important element in the fight against climate change. By analyzing this comparison, it is possible to identify trends and differences in individual countries' approaches to emission reduction. In Poland and the European Union (EU-27), there has been stability in CO_2 emissions per capita, with a constant value of 8 tons per inhabitant. Both Poland and the entire EU maintained a similar average, at 8.6 and 8 tons, respectively, without showing any major changes in the analyzed period.

The United States showed a decrease in emissions from 16 tons per capita in 2017 to 15 tons in 2021, which generates a negative change dynamics of -6.3%. This may be the result of sustainable development activities and investments in renewable energy. China, on the other hand, although still relatively low in emissions when compared to other countries, has shown an upward trend. The increase from 7 to 8 tons per inhabitant between 2017 and 2021 represents a positive dynamic change of 14.3%. This may be due to intensive economic development and increased energy consumption. Finally, Japan showed a stability of 9 tons per capita, with an average value of 8.8 tons. Even though there are no significant changes in emissions, the country can still strive to improve energy efficiency.

Summing up, the analyzed data on carbon dioxide emissions show a varied picture of individual countries' actions to reduce their impact on the environment. The stability of emissions in Poland, the European Union and Japan contrasts with declines in the United States and increases in China, reflecting different priorities in climate and economic policy. **Figure 1** below shows the forecast of CO_2 emissions per capita.

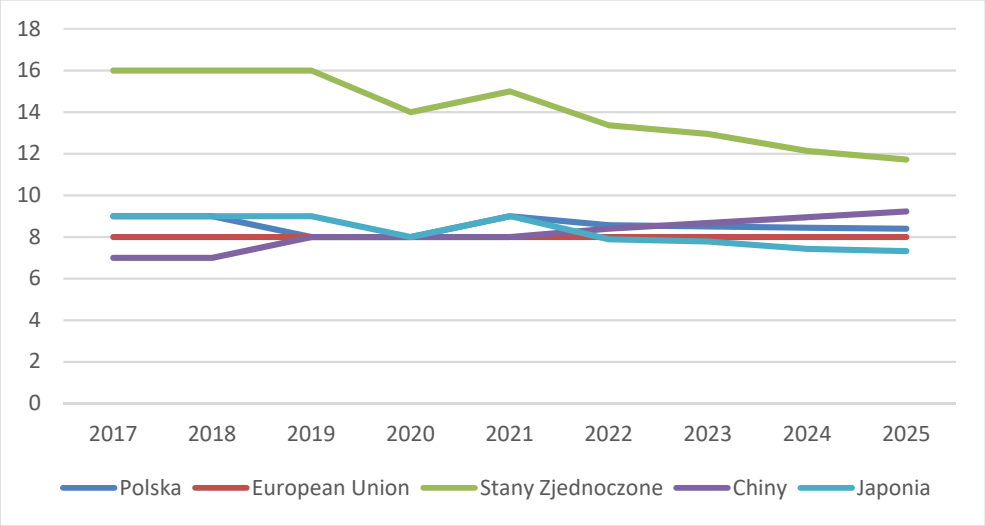

Figure 1. Prognosis of CO_2 emissions (in tones per capita)
Source: Own elaboration

In the case of Poland, CO_2 emissions per person are forecasted to be relatively constant, remaining at the level of 8.39-8.51 tons per person. This suggests that the country is making efforts to stabilize emissions and may be implementing measures to increase energy efficiency. The European Union can generate sustainable CO_2 emissions of 8 tones per person between 2023 and 2025, reflecting the EU's commitment to reducing negative environmental impacts and achieving the Sustainable Development Goals.

In the United States, CO_2 emissions are projected to decline, from 12.95 tons per person in 2023 to 11.72 tons per person in 2025. This may result from actions to reduce emissions and increase the share of renewable energy sources. In the case of China, CO_2 emissions are also expected to decline, from 8.67 tons per person in 2023 to 9.23 tons per person in 2025, which may be the result of its commitment to protect the natural environment despite economic growth. Finally, Japan can maintain relatively low CO_2 emissions, i.e. around 7.32-7.89 tons per person in 2023-2025, most probably due to long-term investments in clean development technologies.

When analyzing the issue of sustainable development and innovation, the consumption of energy from renewable sources was also checked. The relevant data are given in **Table** 7.

Table 7. Energy consumption from renewable sources (kWh per inhabitant)

	2017	2018	2019	2020	2021	Mean	Dynamics of changes between 2017-2021
Poland	1937	1852	2151	2293	2526	2151.8	30.4%
UE-27	5787	6181	6357	6850	6961	6427.2	20.3%
United States	7110	7224	7404	7710	8089	7507.4	13.8%
China	3194	3487	3800	4097	4580	3831.6	43.4%
Japania	3652	3929	3952	4284	4732	4109.8	29.6%

Source: Own elaboration after: https://ourworldindata.org/grapher/per-capita-renewables?tab=chart&time=2017..latest&country=CHN~OWID_EU27~JPN~POL~USA; [accessed: 27.08.2023]

The analysis of the presented data shows the use of renewable energy sources in the surveyed countries, indicating both the progress in sustainable energy production and the growing awareness of global challenges related to climate change. On this basis, it is possible to distinguish differences between countries and their contribution to global efforts for sustainable development. In Poland, energy consumption from renewable sources increased from 1,937 kWh per inhabitant in 2017 to 2,526 kWh in 2021, recording a dynamic increase of 30.4%. This could be due to investments in renewable energy sources, such as wind and solar power and various efforts to reduce greenhouse gas emissions. In the European Union, on the other hand, the average per capita renewable energy consumption reached 6,961 kWh in 2021, with a marked change of 20.3% over the period considered. This confirms the efforts of Member States to increase the share of renewable energy in energy production and to achieve climate goals.

The United States presents renewable energy consumption at the level of 8,089 kWh per inhabitant in 2021, with a growth rate of 13.8%. This state of affairs may be due to the growing role of wind and solar energy in the American energy mix. As for China, although starting from a lower level, the country showed a significant increase from 3,194 kWh per capita in 2017 to 4,580 kWh in 2021, which represents a positive change dynamics of 43.4%. This may be due to national investments in wind and solar energy and initiatives to reduce air pollution. Finally, Japan achieved an increase in renewable energy consumption from 3,652 kWh per capita in 2017 to 4,732 kWh in 2021, recording a visible change of 29.6%. This may be the result of various advances in photovoltaic technologies and emission reduction strategies.

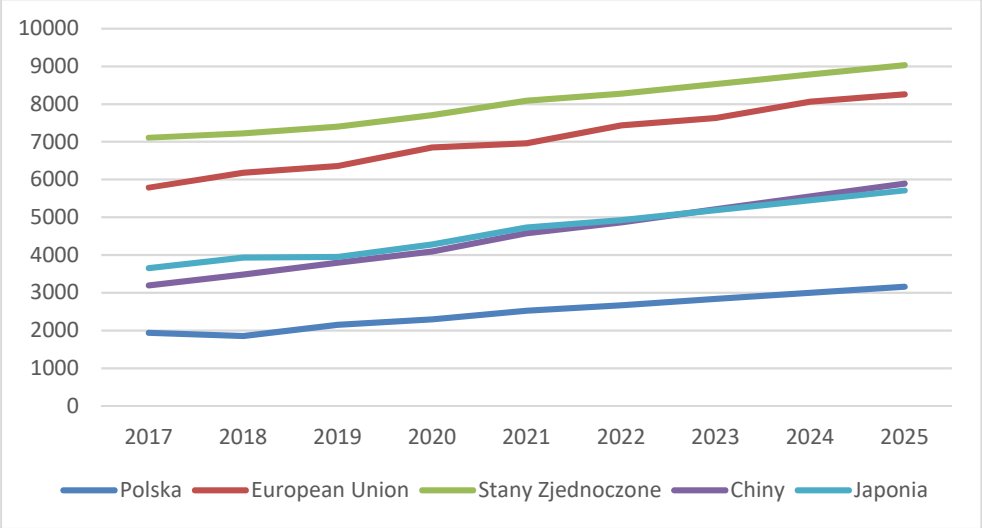

Figure 2. Forecast of energy consumption from renewable sources (kWh per inhabitant)
Source: Own elaboration

In Poland, a constant increase in the consumption of renewable energy is expected, reaching the level of 3,160.93 kWh per capita in 2025 (**Figure 2**). This is a positive step towards increasing the share of renewable energy sources in the national energy mix. The European Union may also continue this trend, as it is predicted that in 2025 one person will consume on average 8,260.57 kWh of energy from renewable sources. This reflects the EU's commitment to sustainable energy development and the growing share of renewable sources.

In the United States, renewable energy consumption per person is projected to increase, reaching 9,033.78 kWh in 2025, being the result of growing interest in renewable energy and investments in its development. As for China, despite its intensive economic growth, the country will strive to increase the consumption of renewable energy, reaching 5,893.90 kWh per capita in 2025. This may illustrateits commitment to green development. Finally, Japan may see an increase in renewable energy consumption per person, reaching 5,709.12 kWh per capita in 2025, while still continuing to invest in clean development technologies and efficient energy use.

Generally speaking, different approaches of the selected countries to energy transformation can be observed. However, the growth in renewable energy consumption in Poland, the EU, the United States, China and Japan clearly reflects global efforts to reduce emissions and sustainably use energy resources, although at different rates and in different contexts.

4. Relationships between energy consumption and selected innovation measures

In the last part of the research, there will be presented the focus on the intriguing issue of the relationship between energy consumption and selected innovation indicators. Exploring these relationships is an important step in understanding how sustainability efforts and innovative approaches can support each other. The analysis of innovation indicators in the context of energy consumption will shed new light on the dynamics of economic development, sustainable production and energy efficiency. By identifying some of the existing connections, it will be possible to determine whether countries achieving a higher level of innovation are also willing to use energy resources more effectively and/or whether modern technologies and inventive approaches influence the development of a more sustainable energy model. **Table 8** below presents the relationships between selected measures of innovation and energy consumption, on the one hand and the results of the Pearson correlation coefficient assigned to them, on the other. For this purpose, average values for the years 2017-2021 were used.

Table 8. Relationships between selected predictors of innovation and measures of energy consumption per capita (average values for the examined period)

Dependency	Correlation result
Patent effectiveness and CO2 emissions per capita	-0.26
Patent efficiency and renewable energy consumption per capita (kWh)	-0.22
Trademark efficiency and CO2 emissions per capita	-0.84
Trademark efficiency and renewable energy consumption per capita (kWh)	-0.47
R&D expenditure and CO2 emissions per capita	0.55
R&D expenditure and renewable energy consumption per capita (kWh)	0.60

Legend: Patent effectiveness should be understood as an indicator of the effectiveness in obtaining patents; at the same time, trademark effectiveness is the effectiveness of activities related to applying for a trademark.
Source: Own elaboration

The results presented in **Table 8** are the result of the analysis of the relationship between innovation rates and energy consumption per capita in the studied countries, when using Pearson correlation and a specific interpretive scale. The obtained correlation values are crucial for quantifying the strength of the relationship between the analyzed relationships.

The first group of relationships examined was the one between the effectiveness of patents and energy consumption. A moderate negative

correlation of -0.26 can be observed between patent efficiency and CO_2 emissions per capita; this may suggest that countries with higher patent efficiency aspire to lower CO_2 emissions per capita and more efficient energy use. A situation like this could indicate that innovation can lead to the creation of greener energy solutions. While examining another group of relationships, this time regarding trademarks in relation to energy consumption, it can be seen that CO_2 emissions per capita show a strong negative correlation with trademark effectiveness (-0.84), which may suggest that the studied countries more focused on trademark protection are, at the same time, more interested in sustainable energy use. The third group of relationships concerns research and development expenditure in relation to energy consumption. These relationships showed a positive but moderate strength, what may indicate more complex interactions between the R&D sphere and CO2 emissions per capita. Nevertheless, in one case, there was noted a clearly noticeable relationship, which should be interpreted as follows: with an increase in expenditure on research and development activities, there also appears an increase in the consumption of energy from renewable sources per capita and vice versa.

Analyzing and interpreting these relationships provides valuable insights into how innovation can influence the more sustainable use of energy resources. However, it should be remembered that these results are only a starting point for further research in other words, more extensive analyzes taking into account the socio-economic context of each country for a more complete understanding of the interactions between these indicators are expected.

5. Discussion of the results

Innovations play a key role in solving problems related to climate change as, for example, emphasized by M.L. Weitzmann (1998). Also S.A. Churchill *et al.* (2019) claim that technological innovation is the key to sustainable resource use and economic growth. The massive analysis carried out by them showed that a strong relationship was observed only in the case of trademark effectiveness and CO_2 emissions per capita (-0.84). As the effectiveness of trademarks increased, CO_2 emissions per capita decreased. In other cases, associations were moderate or weak.

Numerous studies reveal the complex relationship between innovation and greenhouse gas emissions. C. Cheng *et al.* (2019) found mixed effects, with patents and renewable energy affecting emissions differently. In another study, C. Cheng *et al.* (2021) show that innovations improve emissions in some areas but make them worse in others. According to other sources, (c.f. Liu & Dong, 2021), low-carbon innovations have a limited impact on emissions. A.O. Acheampong*et al.* (2022) identify a U-shaped relationship between innovation and emissions. L. Dauda*et al.* (2021)

confirm the inverted U-shape in three developing countries. The research by D. Balsalobre-Lorente*et al.* (2021) reports positive effects of energy innovations on air travel; also J. Gu (2022) associates innovations with emission reduction and moderate relationships with economic development. These findings also highlight regional differences.

In the study by A. Cai*et al*. (2021) interprovincial carbon dioxide emissions in China were found to have a strong spatial effect. Carbon dioxide emissions in this region are not only related to their own factors, but are also influenced by factors of neighboring regions. In particular, green technological innovations and improvements in the industrial structure in neighboring regions have a negative impact on the region's carbon dioxide emissions. R. Miśkiewicz (2021) also wrote in a similar tone, pointing out that the development of information and innovative technologies had a statistically significant impact on greenhouse gas emissions.

Summary and conclusions

The paper analyzes the relationship between sustainable development and innovation, trying to understand how these two spheres interact in the context of various indicators and dynamic changes between 2017 and 2021. The study included selected aspects related to CO_2 emissions per capita, renewable energy use per capita, patent effectiveness, trademark effectiveness and research and development expenditure (as % of GDP). Using Pearson correlations, the analysis identified relationships between these measures.

The aim of these considerations was to identify and quantify the relationship between innovation measures and predictors of sustainable development in selected countries. The results of the analysis showed that there exists a relationship between innovation and CO_2emissions per capita. Countries with higher patent and trademark efficiency tended to have lower CO_2 emissions per capita. This suggests that the development of new technologies and the protection of intellectual property may influence the creation of more ecological solutions and reduce the negative impact on the environment. This analysis allowed for positive verification of two research hypotheses, i.e. H1 and H2.

The analysis of the share of renewable energy in the energy mix, in the context of innovative activities, also provided valuable insights. Countries with increased trademark efficiency were characterized by a greater share of primary energy from renewable sources. This suggests that there is greater efficiency in the use of available renewable energy sources in these countries. However, higher spending on research and development did not lead to a higher share of renewable energy in every case analyzed. This may indicate more complex relationships between investments in innovation and the energy transformation. However, the study

showed that in one case there was a clear relationship between R&D expenditure and the use of alternative energy. It was found that with the increase in expenditure on research and development activities, there is also an increase in the consumption of energy from renewable sources per capita and vice versa; a result like this confirms the positive verification of the third hypothesis - (H3).

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