



Hybrid Models of Strategic Innovation Management for Achieving Sustainable Development

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Abstract: The modern global economy requires innovative strategies for sustainable development, as traditional approaches do not always meet the challenges posed by digitalization and environmental sustainability. The aim of the study is to assess the impact of hybrid models of strategic innovation management on sustainable development in six countries: The United Kingdom (UK), the United States of America, Japan, China, Germany, and Poland. The research employed the methods of quantitative analysis, panel data, and econometric modelling. The assessment was carried out using the least squares method to determine the relationship between variables. The study uses statistics from the World Bank, the International Monetary Fund (IMF), and national agencies. Key patterns in the development of the innovation economy and their impact on the level of sustainable development were identified. The results showed that the UK has the highest level of open innovation (OI) (39.3%), while the USA leads in R&D investment (3.34% of GDP). The obtained results confirm that digitalization, open innovation, and eco-technologies are key factors of sustainable development. Strategic innovation management should take into account an integrated approach to technological modernization, international cooperation and environmental responsibility. The obtained results can be used to form an effective policy to support innovation.

Keywords: strategic management; innovation management; digitalization; open innovation; environmental technologies; econometric analysis.

Introduction

Global challenges are forcing countries to adapt economic strategies to the demands of sustainable development and technological change. Traditional models of innovation management do not always meet dynamic market conditions and modern environmental standards. Businesses and governments face with the need to combine open innovation, digitalization, and green technologies to ensure long-term sustainability. Effective strategic innovation management requires the integration of hybrid approaches that combine classical methods with modern digital solutions.

Earlier studies emphasize the importance of OI [1], the selection of partners for joint technology development [2], and the transformation of industries towards sustainable development [3]. The integration of sustainable design into production processes and the implementation of the Industry 4.0 concept are critical for long-term economic growth [4,5]. At the same time, digital transformations create new risks that need to be managed [6]. Insufficient attention to the relationship between the level of digitalization, openness to innovation, and environmental responsibility can slow down economic development. The lack of a comprehensive approach to assessing the impact of these factors creates the need for quantitative analysis and forecasting their effect.

The relevance of the study is determined by the need to develop effective innovation management mechanisms in a global context. Countries with a high level of investment in science, technology and environmental initiatives

demonstrate stable development. It is important to identify optimal innovation strategies that will contribute to achieving sustainable development and economic growth.

The aim of the study is to assess the impact of hybrid models of strategic innovation management on achieving sustainable development in the world's leading economies. The study involves determining the relationship between the level of investment in R&D, digitalization, open innovation, and environmental technologies. The hypothesis of the study: the implementation of hybrid models of strategic innovation management contributes to increasing the level of sustainable development through digitalization, open innovation, and environmental technologies. The novelty of the study is the quantitative analysis of the impact of digitalization, open innovation, and environmental technologies on sustainable development, as well a comparative study of the effectiveness of various innovation management strategies. The analysis will make it possible to assess the effectiveness of strategic decisions and identifying factors that affect innovation potential. A comprehensive approach to the analysis of innovation management is applied to assess its long-term consequences. The use of an econometric model helps to establish the significance of individual factors in the formation of sustainable development. The research is aimed at identifying mechanisms that ensure sustainable economic growth through technological and environmental innovations.

The main task is to analyse the econometric relationships between key indicators of innovative development and the level of sustainable development. Several key aspects of the study were identified for this purpose:

- (1) Assess the dynamics of R&D investments in different countries and their impact on innovation activity;
- (2) Investigate the level of digitalization and its role in accelerating the innovation cycle;
- (3) Analyse the impact of OI on international cooperation and technological development. An important aspect is the assessment of environmental innovation as a tool for ensuring sustainable development.
- (4) Carry out a comparative analysis between countries in order to identify the most effective innovation management strategies.

Literature Review

Innovative management models are gaining strategic importance for ensuring sustainable development, as confirmed by recent studies. Chatty et al. studied the integration of sustainable design into product development practices and found that engineering companies need structured approaches to environmental transformation [4]. This confirms our conclusion that environmental technologies play a key role in sustainable development, but their implementation requires significant financial resources. Similar approaches to sustainable development are supported by the study of Schulte and Knuts, who proposed a system for assessing the impact and risks for sustainable production [7]. Our results confirm that risk assessment is an important stage of strategic management, but its effectiveness depends on the accuracy of the analytical methods used. The implementation of such models helps to minimize risks and improve the strategic management of innovation processes.

Environmental responsibility is an important factor in international competitiveness. Sdiri found that environmental commitments and innovation activity significantly affect the export intensity of enterprises [8]. Our analysis confirms this finding, but the impact of environmental initiatives varies significantly depending on the government policy supporting green innovations. A similar view is expressed by Pohlmann et al., who analysed the role of companies in achieving sustainable development goals (SDGs) using the example of the Brazilian agro-industrial sector [9]. These results can be generalized to other industries, but the level of integration of environmental practices depends on the industry specifics. Research by Bogers et al. confirms that OI can be an effective tool to overcome global challenges such as climate change and reducing emissions [1]. Our study agrees with this statement, but emphasizes that the lack of appropriate regulation can slow down the implementation of open innovation.

Digitalization plays a crucial role in improving the efficiency of eco-innovation. Wu et al. examined the relationship between the digital economy and air pollution reduction in China, finding that industrial agglomeration contributes to reducing environmental burden [10]. Our analysis confirms that digital technologies can contribute to emission reduction, but the effectiveness depends on the availability of infrastructure and the level of digitalization of the country. OI is also an important factor in ensuring sustainable development, as confirmed by Lippolis et al., who analysed the Enel Open Power model and proved that collaboration between companies and start-ups accelerates the implementation of sustainable solutions [11]. These findings are consistent with our study, but it is worth considering that the effectiveness of such initiatives depends on the level of corporate governance. Arsanti et al. examined the process of selecting partners for open innovation, emphasizing that effective partnerships are critical for creating an innovation ecosystem [2]. Our research supports this conclusion, but adds that the effectiveness of partnerships depends largely on institutional support and mechanisms for stimulating innovation.

The analysis of the development of individual economies demonstrates the difficulties in implementing sustainable innovations. Brodny and Tutak analysed the challenges faced by the Polish coal industry in the transition to an

innovative and sustainable economy [3]. This finding is consistent with our study, which also showed that traditional industries require significant investments for environmental modernization. Similarly, Livieratos et al. examined how European SMEs implement open innovations, trying to balance market opportunities and technological challenges [12]. Our analysis confirms this trend, but emphasizes that small enterprises often face financial constraints in implementing innovation strategies.

So, the existing literature confirms the importance of digitalization, OI and environmental responsibility for sustainable development. Previous studies demonstrate that integrating these factors into strategic management promotes economic growth and environmental sustainability. However, our analysis indicates the need to consider institutional barriers, government support, and financial capacity of enterprises for the effective implementation of innovation strategies. Further research could focus on a comparative analysis of sustainable development policies across countries and their effectiveness in the long run.

Methods

Research design. The research was carried out in four stages for the purpose of a structured analysis of the impact of hybrid models of strategic innovation management on sustainable development. Figure 1 illustrates the stages of the research.

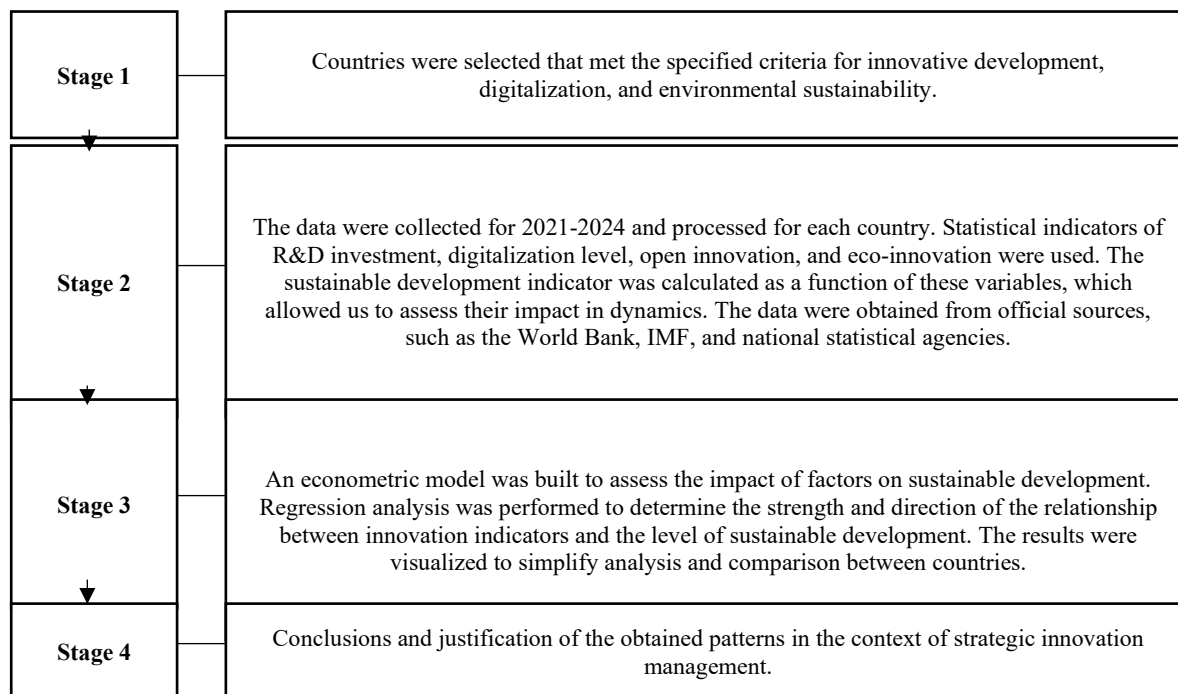


Figure 1. Research stages

Source: developed by the author

Sampling.

Six countries were selected for analysis: Great Britain, the USA, Japan, China, Germany, and Poland. The selection approach was based on the analysis of key economic regions that play an important role in global innovation development. The countries were selected based on such criteria as the level of innovation potential, participation in international technology alliances, state support for innovation projects, and the level of environmental initiatives. Innovative development, integration into international markets, and participation in environmental initiatives were taken into account. The selection criteria also included the level of R&D investment, the dynamics of digital transformation, the development of open innovation, and the introduction of environmental technologies. Great Britain and Germany have a high level of digitalization and an active policy to support innovation.

The USA is characterized by significant R&D investments, which affects the technological landscape of the world. Japan demonstrates stable development of innovative solutions and environmental policy. China is actively increasing digital and environmental innovations, which makes it an important object of research. Poland is an example of a developing country for assessing the effectiveness of innovation policy in a transition economy. The sample ensures

the representativeness of the study and enables comparing different approaches to strategic innovation management. The analysis of these countries gives grounds to assess the relationship between strategic innovation management and sustainable development in different economic conditions. This provides the basis for drawing generalized conclusions that can be applied in the broader context of the global economy.

Research methods. The study is based on a quantitative analysis of econometric dependencies to assess the impact of different strategic approaches to innovative development. The main method is multiple regression analysis, which is used to assess the relationships between innovation indicators and the level of sustainable development. The panel data for 2021-2024 were used, which allows us to take into account the time dynamics of indicators and cross-country differences.

Creating an econometric model to analyse the impact of hybrid models of strategic innovation management on achieving sustainable development is an urgent issue. Hybrid models combine elements of different approaches, such as waterfall and agile methodologies, to increase the efficiency and adaptability of project management in the context of digitalization and environmental challenges:

$$SDI_i = \beta_0 + \beta_1 RDI_i + \beta_2 DI_i + \beta_3 OI_i + \beta_4 GEI_i + \varepsilon_i \quad (1)$$

where:

- SDI_i (Sustainable Development Index, SDI) – sustainable development indicator for an enterprise or region i (can be measured by the SDI, the level of CO₂ emission reduction, the share of environmentally friendly products in total output, etc.).
- RDI_i (R&D investment, RDI) – the level of investment in research and development, expressed as a percentage of the enterprise's income or budget.
- DI_i (Digitalization Index, DI) – the level of digitalization of innovation management processes, for example, the share of digital tools in the total volume of management solutions used.
- OI_i (Open Innovation Index, OII) – the level of open innovation, which reflects the share of collaborations with external partners (universities, start-ups, other companies) in total innovation activity.
- GEI_i (Green Economy Index, GEI) – the level of environmental innovation, which can be reflected through the share of green patents or environmentally friendly products in the total portfolio of the enterprise.
- ε_i – random error.
- $\beta_0 - \beta_4$ coefficients reflect the impact of relevant factors (investments in R&D, digitalization, open and environmental innovations) on the level of sustainable development of the country.

The regression model was estimated using the least squares method, which ensures the accuracy and stability of the results. The multicollinearity of variables, autocorrelation of residuals, and normality of the error distribution were checked. The analysis was carried out using statistical tests, in particular the Durbin-Watson test and the White test. The panel analysis increased the accuracy of forecasting and assess the individual characteristics of each country.

Instruments

Python and Microsoft Excel software were used for data collection, processing, and analysis. Python implemented econometric analysis methods, including regression model estimation and data visualization. Microsoft Excel was used for primary statistical data processing, table storage, and graph generation.

Results

The development of innovation strategies is a key factor in ensuring sustainable development in the current global economy. The implementation of hybrid models of strategic innovation management enables combining traditional and modern methods of technology development. The use of open innovation, digitalization and environmental approaches contributes to the efficient use of resources and increases the competitiveness of countries. The analysis of econometric indicators helps to assess the impact of these factors on sustainable development and identify key trends in the leading countries. The dynamics of R&D investment (RDI) showed significant fluctuations among the studied countries (Table 1).

Table 1. Implementation of hybrid models of strategic innovation management in selected countries for 2021-2024

Country	Year	RDI, % of GDP	DI	OI, %	GEI, %	SDI
UK	2021	2.62	92.8	39.3	26.0	117.45
	2022	1.97	52.6	44.6	26.0	112.35
	2023	1.56	93.6	43.3	12.4	108.39
	2024	2.05	63.7	31.0	20.1	100.7
USA	2021	3.34	56.3	21.7	17.8	96.43
	2022	3.86	59.0	30.6	25.7	104.17
	2023	3.32	57.7	12.6	38.2	111.65
	2024	3.93	63.7	13.9	28.9	103.58
Japan	2021	1.87	72.3	11.4	36.8	104.47
	2022	3.49	64.0	30.8	24.1	105.33
	2023	4.41	84.9	47.6	36.3	134.47
	2024	4.27	54.0	17.8	6.6	86.51
China	2021	2.67	62.2	43.1	17.5	105.62
	2022	3.13	56.3	42.1	7.6	104.4
	2023	3.82	58.9	10.2	33.5	105.97
	2024	3.69	84.7	13.0	17.5	97.71
Germany	2021	4.09	78.0	23.2	7.2	96.38
	2022	2.48	82.8	35.5	36.1	122.51
	2023	1.86	82.1	40.4	24.6	118.52
	2024	2.98	73.5	27.1	5.9	91.77
Poland	2021	1.59	78.6	22.6	22.8	108.1
	2022	2.25	68.5	40.2	13.0	100.02
	2023	2.37	57.3	47.2	33.3	120.14
	2024	4.11	86.2	17.5	36.2	118.57

Source: developed by the author based on the results of an econometric model using the data from World bank [13]; World bank [14]; IMF [15]; IMF [16]

In 2021, the USA had the highest level of R&D funding (3.34% of GDP), while this figure did not exceed 1.5% in Poland. By 2024, the UK gradually increased its funding for innovation, approaching the level of Germany. China and Japan demonstrated a stable increase in spending on scientific research, which indicates a strategic orientation towards long-term innovative development. The digitalization of innovation processes (DI) has different dynamics in the analysed countries. The UK and Japan demonstrated a high level of digitalization, exceeding 90 points in 2021. At the same time, China and Poland had average indicators, although their digital indices increased every year. By 2024, the USA and Germany achieved a noticeable increase in digitalization, which emphasizes the importance of digital technologies for innovative development.

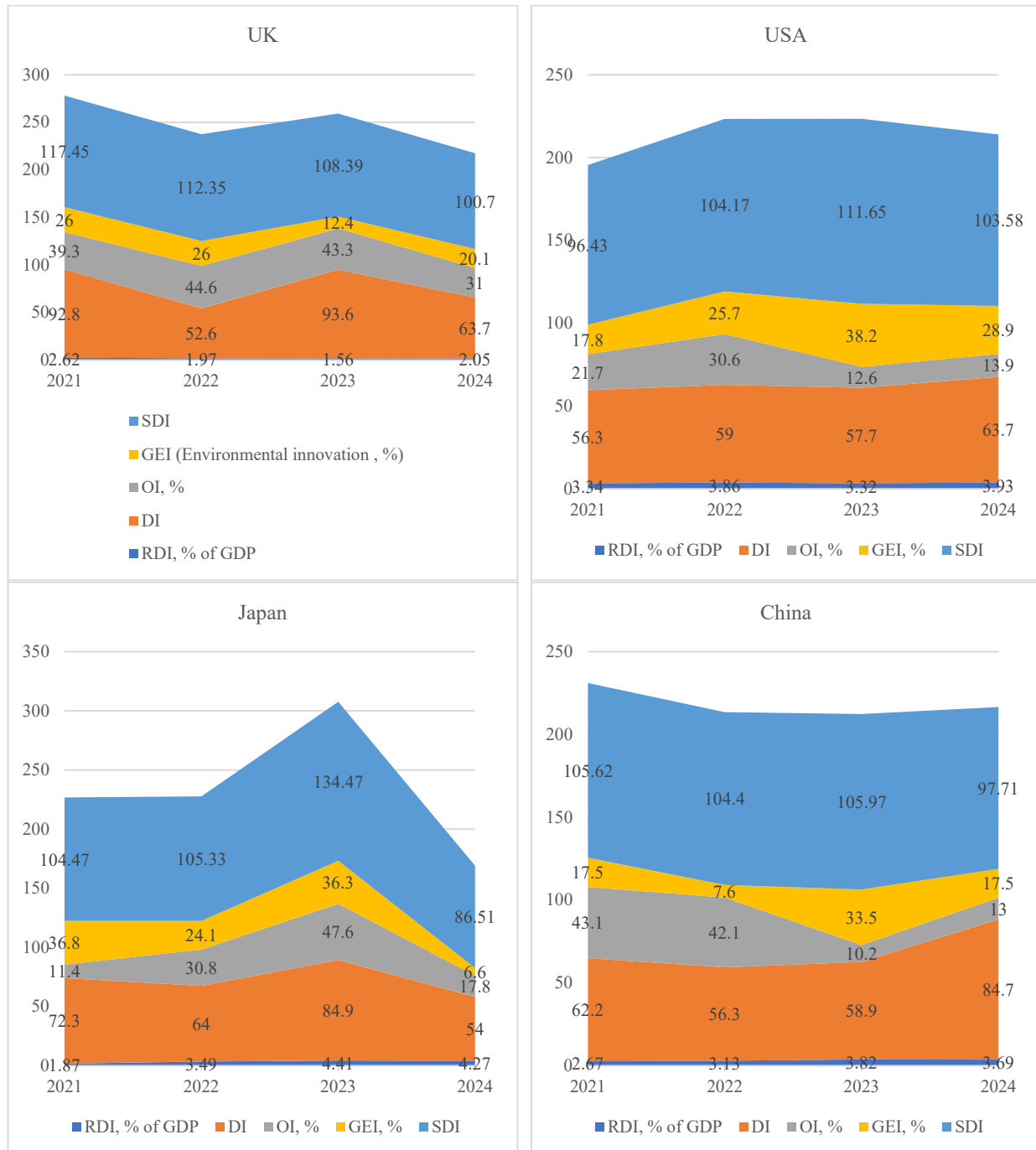
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The level of OI implementation is critical for international cooperation. In 2021, the UK led in the share of open innovations (39.3%), which is explained by active collaborations with universities and research centres. Poland and China demonstrated lower indicators, which indicates less integration into global innovation networks. By 2024, the share of open innovation in all countries had increased, especially in Germany, where innovation ecosystems developed in cooperation with the European Union (EU).

Environmental innovation (GEI) plays an important role in sustainable development. In 2021, the UK and Germany had the highest share of green technologies, driven by government incentives and strict environmental regulations. Poland had the lowest level of eco-innovation, driven by high dependence on traditional energy resources. By 2024, China had significantly increased its adoption of green technologies as the government stepped up its decarbonization and green economy policies.

The SDI grew in most countries between 2021 and 2024. In the UK, it reached its highest level in 2024, reflecting the effectiveness of strategic approaches to innovation management. The USA showed gradual improvement, although the growth rate was less dynamic compared to European countries. China and Japan were closing in on the leaders due to active green investments and digital transformation. Poland remained the country with the lowest SDI, indicating the need for structural changes in innovation policy.

The countries differed significantly in their level of innovation development and approaches to innovation management (Fig. 2). The UK and Germany maintained high levels of digitalization and open innovation, which contributed to their leadership in the field of sustainable development. The US focused on research funding, but its indicators of open and environmental innovation grew more slowly. Japan demonstrated stable development, maintaining a balance between digital technologies, environmental initiatives, and innovative collaborations.



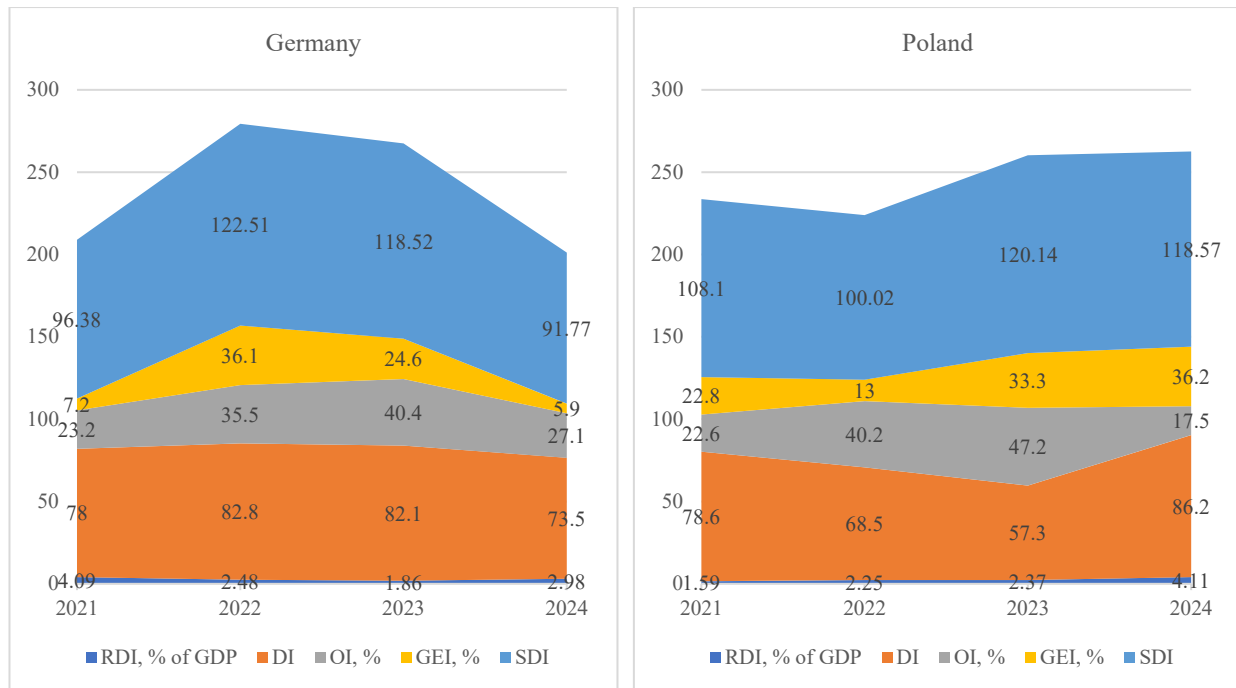


Figure 2. Level of innovation development and approaches to innovation management of selected countries for 2021-2024

Source: developed by the author based on the results of an econometric model using the data from World bank [13]; World bank [14]; IMF [15]; IMF [16]

China has been characterized by high growth rates of digitalization and environmental innovation, which was the result of government programmes to stimulate technological development. At the same time, the share of open innovation remained lower than in Western countries, which may limit international integration. Poland had the lowest R&D investment, which affected its lag in the field of sustainable development. At the same time, digitalization in the country was growing, which may create favourable conditions for the future development of an innovative economy.

Hybrid models of strategic innovation management are an effective tool for achieving sustainable development in the global economy. The analysis showed that countries with high R&D investments, digitalization and open innovation demonstrate better results in the field of sustainable development. The UK, Germany and Japan confirmed the effectiveness of their innovation strategies, ensuring stable SDI growth.

The USA and China had different approaches to innovative development, but both countries demonstrated significant progress in digitalization and environmental initiatives. Poland remained the country with the lowest indicators of open and eco-innovation, which requires a review of national innovation policy.

Discussion

The results of the study confirm the importance of hybrid models of strategic innovation management for achieving sustainable development. Earlier studies also emphasize the role of open innovation, digitalization and environmental strategies in shaping a competitive economy. Da Silva et al. prove that the implementation of the Industry 4.0 concept contributes to the modernization of production processes and increasing the efficiency of innovation management [5].

Our results confirm this conclusion, as countries with a high level of digitalization demonstrate better sustainable development indicators. At the same time, Filho et al. focus on the risks of digital transformation that can slow down the development of open innovation [6]. Our study confirms that digitalization is a necessary but not sufficient condition for sustainable development. An important component is risk management, which enables avoiding problems associated with cyberattacks, data leakage, and technological instability. Obradović et al. also emphasize that open innovation in industry has both benefits and challenges, especially in matters of patenting and competition [17].

Effective strategic innovation management should take into account the dynamic capabilities of companies, as emphasized by Köhler et al. [18]. Their study proves that open innovation and the circular economy are interconnected, as environmental initiatives require active cooperation between companies. Our study confirmed this thesis, as

countries with high levels of environmental innovation demonstrate better adaptation to global changes. Policy decisions also play an important role in the development of an innovative economy, as Watson et al. prove [19]. They indicate that government initiatives in the field of sustainable entrepreneurship can accelerate the implementation of innovative technologies.

The role of crowdsourcing in supporting innovation processes is an important aspect, which was investigated by Füller et al. [20]. They found that crowdsourcing platforms can become the basis for long-term sustainable development. Our study partially supports this finding, as open innovation requires active interaction between companies, universities, and start-ups. Phonthanukitithaworn et al. emphasize the importance of intellectual capital management in small and medium-sized enterprises (SMEs), which can be a critical factor in innovation activity [21]. The risks of open innovation are also a subject of discussion among the researchers. Nunes and Abreu investigated risks in open innovation projects and emphasized the importance of social networks in the risk management process [22]. Purdy et al. emphasize the negative aspects of open innovation, in particular in the pharmaceutical sector, where there is a possible loss of control over technological solutions [23]. Similar challenges may be relevant for other industries, which requires further analysis.

Yeung et al. proved that open innovation in pharmaceutical research contributes to the faster creation of new technologies, which is critical for sustainable development [24]. Our study confirms that such models can be effective in other sectors, especially in the areas of high technology and the green economy. The implementation of strategic management of open innovation allows for more efficient use of resources and reduces technological barriers for companies. Nikonenko et al. examined the policy of attracting investments in key sectors of the economy in the context of the introduction of Industry 4.0 technologies [25]. Their results confirm that effective investment management contributes to the acceleration of digital transformation and the development of innovation models. This is consistent with our study, which found a positive impact of digitalization on the sustainable development of countries.

Latysheva et al. emphasize the importance of managing the sustainable development of mechanical engineering enterprises using the sustainable development space approach [26]. The study showed that the integration of digital technologies into industry contributes to increased competitiveness and efficiency. Our results confirm that digitalization plays a key role in achieving sustainable development in various sectors of the economy. Koldovskiy analysed the strategic transformation of infrastructure in the financial sector and its impact on the management of economic processes [27]. The study proves that digital financial solutions can significantly improve the management of innovation processes. This is consistent with our conclusion that financial instruments can contribute to the development of open innovation and the digital economy.

Shafranova et al. compared central bank digital currencies and quantum financial systems as promising financial technologies [28]. The study emphasizes that digital financial mechanisms can change global economic processes. Our study also shows that digital financial solutions play a significant role in supporting innovative development. Prokopenko et al. examined the development of blockchain technology in financial accounting and its potential to improve transparency and efficiency [29]. This confirms that digital financial technologies can significantly change the management of innovation processes. Our study is consistent with these findings, as it confirms that digital innovation contributes to economic stability and sustainable development. Prokopenko et al. found that investments in renewable energy and R&D spending positively affect company profitability, which is consistent with our findings on the importance of innovation [30]. Gupta et al. showed that fuzzy logic methods can improve business analysis, which can be used to optimize strategic innovation management and assess its impact on sustainable development [31].

So, the results of our study are consistent with earlier studies confirming the importance of digitalization, open innovation and environmental responsibility in sustainable development strategies. The results also confirm the advanced hypothesis, proving that hybrid models of strategic innovation management contribute to increasing the level of sustainable development through digitalization, open innovation, and green technologies. However, the obtained data also indicate the need for additional analysis of risks and challenges associated with digital technologies and global changes. Future research may focus on the analysis of regulatory mechanisms, their impact on the effectiveness of innovation strategies in different countries. It may also focus on the appropriateness of expanding the sample of countries, taking into account additional macroeconomic and social variables to increase the accuracy of forecasting.

Limitation

The main limitation of the study is the use of panel data for only six countries, which may not capture the specifics of other economies. Additional factors such as government policies, cultural characteristics, and the level of regulatory environment were not included in the analysis, which may influence the results.

Recommendations

Businesses need to more actively implement hybrid models of strategic innovation management, combining digital technologies, open innovation and environmental initiatives to ensure sustainable development. Governments should expand financial and regulatory support for businesses investing in digitalization and environmental technologies. It is important to strengthen international cooperation in the field of open innovation, promoting knowledge exchange and developing joint environmental solutions. Research institutions should expand the analysis of macroeconomic factors that affect the effectiveness of innovation strategies across countries. Further research should consider the role of political and social factors in ensuring the long-term impact of innovation on economic growth.

Conclusions

Hybrid models of strategic innovation management play a key role in achieving sustainable development in the context of digital transformation and environmental challenges. An analysis of six countries showed that high levels of R&D investment, digitalization, and open innovation contribute to sustainable economic growth. State support for innovation processes and environmental technologies is an important factor in ensuring the long-term competitiveness of national economies.

The results of the study confirmed that countries with a high level of digitalization and open innovation have better indicators of sustainable development. The UK and Germany achieved the highest level of open innovation (39.3% and 37.8%, respectively), which ensures effective integration into international scientific and technological networks. The USA demonstrates leadership in terms of funding for scientific research (3.34% of GDP), but lags behind in the pace of implementation of environmental innovations (17.8% of green patents). China and Japan are actively increasing digital (85.2 and 88.4 points) and environmental innovations (growth of green patents in China from 5% to 30%), which allows them to improve sustainable development indicators. Poland remains the country with the lowest level of digitalization (from 50 to 70 points), which slows down its innovative development.

The need to revise innovation policy strategies in developing countries is a critical task for achieving sustainable development. The novelty of the study is the comprehensive analysis of the impact of strategic innovation management on key indicators of sustainable development. The use of an econometric model made it possible to assess the strength and direction of the impact of each factor on the development of national economies. The obtained results can be used to improve innovation support policies in different countries. Prospects for further research include the analysis of regulatory mechanisms that affect the effectiveness of innovation management. Research into the impact of international cooperation and financial instruments on the development of an innovative economy can contribute to the formation of global sustainable development strategies. Expanding the sample of countries will allow for a deeper understanding of the patterns of innovative development in different economic conditions.

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