ECO-INNOVATIONS DIFFUSION NETWORK IN GREEN MANAGEMENT PRACTICES

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Abstract
Countries are facing interconnected and cascading crises, including COVID-19, climate change, wars and military conflicts, and disruptions in geopolitics. To address these global challenges, it is necessary to introduce eco-innovations, and implement renewable energy. The purpose of the article is to analyze the countries' eco-innovative development, determine the impact of factors on alternative energy sources consumption, and consider models for eco-innovation network management. The dynamics of the Global Innovation Index, the European Innovation Scoreboard, and the Eco-Innovation Index were analyzed. The research implements the analysis of 27 EU countries for the period 2013-2020 by indicators that influence the eco-innovations development. The model of the impact of countries' investment development and economic growth indicators (such as foreign direct investment; GDP per capita), management level and the willingness of the government to invest in eco-innovation (total tax and contribution rate; government effectiveness; control of corruption; rule of law; research and development expenditure), and the level of income inequality (income share held by highest 10%; Gini index) on the consumption of alternative energy sources, energy-efficient technologies, and waste management and recycling implementation was built. The linear and cybernetic models for eco-innovation network management were considered. The pace of eco-innovation is strongly influenced by the effectiveness of state eco-innovation policies, the availability of a comprehensive information base, and the mechanisms of interaction between the science and production sectors. Effective eco-innovation networking implies that between the participants there are different types of relationships, the main of which are economic; legal; administrative; technological; social; and informational.
Keywords: alternative energy sources; eco-innovations; green management; interaction; global challenges

1. INTRODUCTION

Over the next decade, the most serious global risks will include extreme weather events, critical change to Earth systems, biodiversity loss and ecosystem collapse, natural resource shortages, misinformation and disinformation, adverse outcomes of AI technologies, involuntary migration, cyber insecurity, societal polarization, pollution (Global Risks Report, 2024). Given these global challenges, the production and adoption of eco-innovations are becoming increasingly vital, with innovation playing a central role in addressing these risks. Furthermore, global challenges and crises frequently act as catalysts for transformative innovations; as a counterforce to crises, innovation drives breakthroughs that help surmount these obstacles. These opportunities not only offer the chance to build resilience and mitigate climate disaster but also to spur economic and technological development, allowing developing countries to "leap" out of the cascade of crisis and move forward (Technology and Innovation report, 2023). As the natural environment increasingly suffers from the loss of biodiversity, pollution, and climate change, the relationship between eco-innovation performance, environment sustainability, countries' economic and management levels, and the willingness of the government to invest in eco-innovation grows in importance. Environmental pollution and climate change, military conflicts and wars leading to violations of energy security and the energy crisis require an analysis of the production and consumption of alternative energy sources. Therefore, the purpose of the article is to analyze the countries' eco-innovative development, determine the impact of factors on the consumption of alternative energy sources, and consider models for eco-innovation network management.

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2. LITERATURE REVIEW

Researchers from different countries of the world are engaged in the study of eco-innovations development, implementation, and diffusion at the corporate, state, and global levels. We analyzed Scopus database for the period 2000-2024 and for the period 2020-2024. In the Scopus database for the period 2000-2024, there are 2136 documents on the "Eco-innovation" request, and for the period 2020-2024 – 1054 documents, which shows an almost doubling of growth over the last 4 years, which indicates both the expansion of the database itself and the relevance of this issue. Co-occurence network for 2020-2024 is presented in Figure 1, where we can see the most frequently occurring keywords in publications during this period.

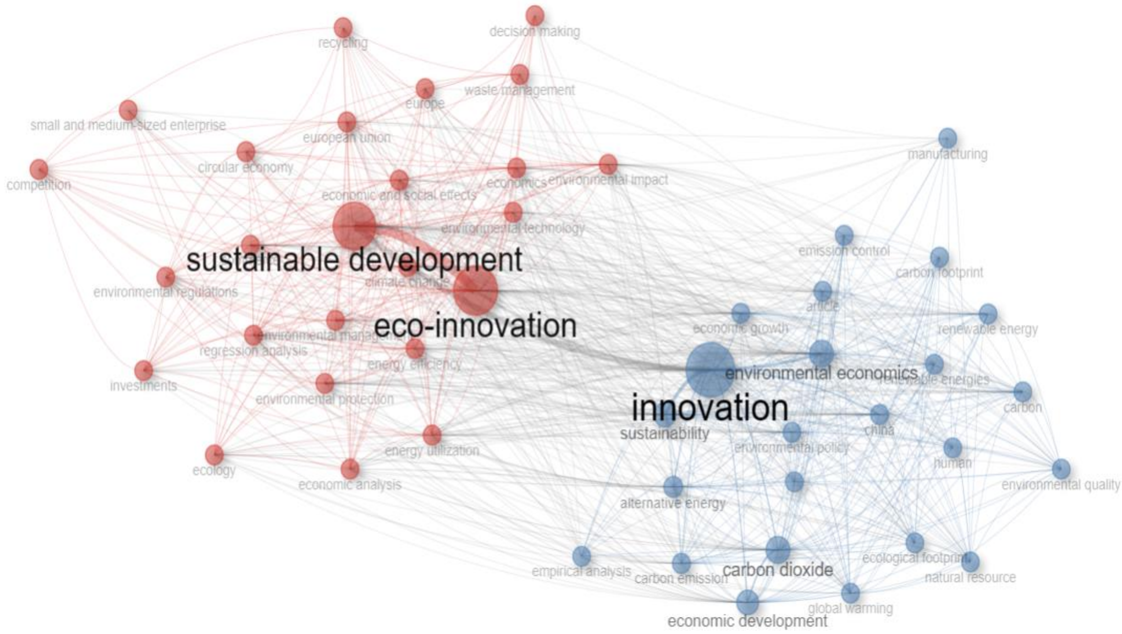

FIGURE 1 – CO-OCCURENCE NETWORK ON THE "ECO-INNOVATION" REQUEST FOR THE PERIOD 2020-2024

The most global cited papers concerning eco-innovations which were published in 2020-2024 are presented in Table 1.

TABLE 1 – THE MOST GLOBAL CITED PAPERS CONCERNING ECO-INNOVATIONS IN 2020-2024

Author	Year	Journal	Total Citations
Khan Z.	2020	Science of the Total Environment	453
Khan Z.	2021	Energy Economics	386
Ahmad M.	2021	Sustainable Cities and Society	265
Cheng Y.	2021	Technological Forecasting and Social Change	243
Ding Q.	2021	Sustainable Production and Consumption	235
Chien F.	2021	Journal of Environmental Management	229
Iqbal N.	2021	Journal of Environmental Management	192
Cainelli G.	2020	Research Policy	181
Su CW.	2021	Science of the Total Environment	178
Li J.	2020	Journal of Environmental Management	175
Tao R.	2021	Journal of Environmental Management	157
Ji X.	2021	Sustainable Development	156
Ahmad M.	2022	Journal of Environmental Management	147
Wang L.	2020	Journal of Environmental Management	134
Ali S.	2021	Sustainable Development	124
Scarpellini S.	2020	Sustainability Accounting, Management and Policy Journal	118
Khan Z.	2020	Energy	114
Sun Y.	2021	Journal of Environmental Management	109
Scarpellini S.	2020	Business Strategy and the Environment	98
Chien F.	2021	Journal of Environmental Management	97

Source: own processing based on Scopus database

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Khan et al. (2020) found evidence of a stable long-term interconnection between CO2 emissions, trade, income, environmental innovation, and renewable energy consumption. Over the long run, imports and income contribute to an increase in consumption-based carbon emissions, while exports, environmental innovation, and renewable energy consumption play a significant role in reducing these emissions.

Hajdukiewicz and Pera (2023) analyzed the European Union countries' eco-innovation performance, identified key areas for improvement in states with lower scores. Their findings indicate that, although most countries within the group of catching-up eco-innovators have made progress in overall eco-innovation performance, they have not significantly narrowed the innovation gap with leading states. The classification of these countries has largely remained unchanged over the past decade. This highlights the need for greater effort, particularly in specific thematic areas, to enable these countries to advance to the level of average or leading eco-innovators. The strongest correlations between the Eco-Innovation Index and certain subindexes indicate that key areas for improvement include total R&D personnel and researchers, eco-innovation-related patents, energy productivity, and the adoption of sustainable products by SMEs. Additionally, Smol et al. (2017) explore circular economy indicators related to eco-innovation across European regions.

To classify countries into each eco-innovation level, (Domaracká et al., 2023) looked at the following variables: eco-innovation inputs, eco-innovation activities, environmental outcomes, socio-economic outcomes, and the eco-innovation index itself. They found that there are significant differences between countries. As they conclude, there are several reasons for this, but one of them is the lack of communication, coordination, and synergy between institutions, government, and SMEs, which are crucial eco-innovation drivers.

Jang et al. (2015) analyze Asian countries' eco-innovation's instruments and find that while there are some similarities in policy approaches across the region, there are also notable differences.

Given the balance between a technology push (supply side) and a market pull (demand side) in policy instruments for eco-innovation, 17 Asian countries were identified by four categories: leaders, followers, loungers, and laggards. Their research contributes to facilitating and diffusing eco-innovation toward sustainability in Asia.

Adomako and Nguyen (2023) examine the impact of social legitimacy on eco-innovation and the moderating roles of green management and institutional pressure. Their results indicate that social legitimacy positively relates to eco-innovation. In addition, results show that the impact of social legitimacy on eco-innovation is moderated by green management practices such that the relationship is amplified when green management is high. Finally, in a three-way interaction effect, they demonstrate that the moderation of green management practices on the linkage between social legitimacy and eco-innovation is enhanced when institutional pressure is greater.

Božić and Botrić (2017) explore the motives of innovators in Croatia to develop eco-innovations. Their results have shown that eco-innovations are developed in response to regulations; implying that policymakers should be careful in designing instruments and measures. The following innovation activities are significantly related to eco-innovation: increase of market share, improvements in health protection and reduction of labour costs.

The logit models were developed to verify the impact of a circular economy on eco-innovation development by (Szczepańczyk, 2022). Peyravi and Jakubavičius (2022) in their research try to establish the criteria for ranking the drivers of eco-innovation adoption using the multi-criteria SAW method. Research findings indicate the nexus between the drivers in eco-innovation and social behavior, eco-design, infrastructural changes, and political approaches. Their research provides a comprehensive framework for understanding the drivers of eco-innovation towards a circular economy with regard to organizational capabilities and exploitative strategies.

Xavier et al. (2020) systematize eco-innovation practices through a maturity model, in order to provide a guide to holistic integration and evolution of organizational maturity. The results and contributions that constitute the originality of this research stand out: guide to eco-innovation practices; maturity levels of eco-innovation; method to evaluate the organizational performance of eco-innovation. The model was improved through expert evaluation using the Delphi Method, which allowed the authors to increase its validity and reliability.

Sehnem et al. (2016) propose such types of eco-innovation: product, process, organizational, marketing, social, system. For example, for product eco-innovation they propose to focus on the development of standardized products and rework, launch green products, focus on eco-design, replace materials used in the manufacture of products (emphasis on reuse, recycling and closed production cycles), use biodegradable and environmentally friendly packaging, join eco-labelling, eco-labels, etc.

Hroncova et al. (2017) analyze and assess the eco-innovation implementation in Slovakia's most energy-intensive sectors, as well as compare the EU countries' eco-innovation performance. The paper highlights the economic and environmental benefits that businesses can gain from adopting eco-innovation, confirming a link between investments in environmental technologies and increased sales of eco-friendly products and services. The authors also identify possibilities for further eco-innovations' development.

Loučanova and Nosáľová (2020) estimate the current situation of eco-innovation's development in Slovakia too. Their results showed that, in general, Slovakia is in the group of countries that are moderate innovators. The study suggests that eco-innovation generally has a positive impact on the companies' environmental, economic, and social growth that progressively embrace sustainable development.

Loučanová et al. (2022) implemented a selection of parameters for evaluating ecological innovations in terms of sustainability in Slovakia within the Kano model. The selection of parameters was inspired by the methodology for assessing the sustainability of buildings – the CESBA methodology, which serves to document and evaluate the energy and ecological qualities of buildings. The authors selected and refined parameters that reflect the most current issues faced by Slovak households. These include: perceptions of innovations in thermal insulation; ecological heating; electricity and water conservation; use of local, natural, and renewable materials; recycled and recyclable materials; low-emission materials; electric and hybrid cars; internal combustion engine vehicles; and eco-innovation in public transport.

The results point to the fact that Slovak respondents are largely unaffected by ecological innovations, but they perceive the use of cars with an internal combustion engine as a mandatory requirement; innovations in thermal insulation, the use of natural and renewable materials and mass transport are attractive requirements for the respondents. Heating and use of recyclable materials are one-dimensional requirements. Despite the large number of studies by authors related to eco-innovations, including in the Slovak Republic, the dynamics of the eco-innovations development and diffusion require analysis, and methods of interaction between participants in the diffusion network require improvement. The indicators (factors) influencing the consumption of alternative energy sources and determining the strength and nature of their influence on changes in consumption remain insufficiently studied.

3. METHODOLOGY AND RESEARCH METHODS

The dynamics of the Global Innovation Index, the European Innovation Scoreboard, and the Eco-Innovation Index in 2013-2023 were analyzed. Such methods as logical, comparative, graphical, correlation and regression were used in this research.

However, for modeling the time interval 2013-2020 was taken, since at the time of the study not all indicators were publicly available for 2021-2023. We take the data from Eurostat Database, Our World in Data, and World Bank. Thus, the research implements the analysis of 27 EU countries for the period 2013-2020 by indicators that influence the eco-innovations development (namely, consumption of alternative energy sources, energy-efficient technologies and waste management and recycling implementation (AEWR)): foreign direct investment (FDI); GDP per capita (GDP); total tax and contribution rate (TAX); government effectiveness (GOVEFF); control of corruption (CC); rule of law (RLAW); research and development expenditure (RD); income share held by highest 10% (ISHIGH), Gini index (GINI). These indicators can have an ambiguous impact on the development of eco-innovations, so the study of their influence is urgent. The choice of these indicators is justified by the following. The indicators include the country investment development and economic growth indicators (FDI, GDP); management level and the willingness of the government to invest in eco-innovation (TAX, GOVEFF, CC, RLAW, RD); and the income inequality level (ISHIGH, GINI), which demonstrate income inequality increasing and the significant carbon footprint of the top 10% richest people in various countries, according to (World Inequality Report, 2022). While rich people can invest more in eco-innovation, they also tend to increase consumption and pollution.

GOVEFF reflects perceptions of the public services quality, the civil service quality and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. CC indicator measures perceptions of the extent to which public power is used for private gain, encompassing both petty and large-scale corruption, as well as the "capture" of the state by elites and private interests. RLAW indicator captures perceptions of the degree to which people have confidence in and adhere to the society rules, including the quality of contract enforcement, property rights, police, and courts, and also the likelihood of crime and violence. GOVEFF, CC, and RLAW are expressed as percentile ranks among all countries, ranging from 0 (lowest) to 100 (highest) (Worldwide Governance Indicators, 2024).

Income share held by highest 10% is percentage share of income or consumption that accrues to the 10th (wealthiest) decile. The Gini index is a extent of income inequality within a country, with a value of 0 indicating perfect equality (equal distribution of income across the population) and a value of 100 indicating absolute inequality (all income belongs to one person) (Metadata Glossary, 2024).

Descriptive characteristics of the indicators are presented in Table 2.

TABLE 2 – DESCRIPTIVE CHARACTERISTICS OF THE INDICATORS THAT INFLUENCE THE ECO-INNOVATIONS DEVELOPMENT

Characte-ristic	Indicator								
	FDI	**GDP**	**TAX**	**GOVEFF**	**CC**	**RLAW**	**RD**	**ISHIGH**	**GINI**
Min.	-3.300e+11	7075	18.40	28.10	44.29	49.05	0.3816	18.30	20.90
1st Qu.	9.591e+08	17641	31.00	64.45	62.29	68.93	0.8939	22.90	27.20
Median	3.862e+09	25885	42.35	73.33	76.67	82.51	1.3227	24.25	30.70
Mean	1.628e+10	33703	41.12	72.16	77.00	80.79	1.6258	24.49	30.87
3rd Qu.	1.750e+10	46778	49.10	84.37	91.55	92.11	2.2295	25.90	34.40
Max.	3.330e+11	123679	71.30	98.10	100.00	100.00	3.5272	32.60	42.10

Source: own processing

For analyzing the FDI, GDP, TAX, GOVEFF, CC, RLAW, RD, ISHIGH, GINI on consumption of alternative energy sources, energy-efficient technologies and waste management and recycling implementation (AEWR) the ordinary least squares (OLS) method and the panel data method (with fixed and random effects) were realized and then the most relevant model is selected.

The research is grounded in the validation of such empirical hypotheses:

Hypothesis 1. The most significant indicators for the consumption of alternative energy sources, energy-efficient technologies, and waste management and recycling implementation are GDP per capita, control of corruption, rule of law, research and development expenditure, income share held by highest 10%, and Gini index.

Hypothesis 2. There is significant correlation between government effectiveness, control of corruption, rule of law, research and development expenditure, and consumption of alternative energy sources, energy-efficient technologies, and waste management and recycling implementation.

Hypothesis 3. The eco-innovation diffusion combines interrelated elements: the eco-innovation itself and practical activity; means of communication; implementation time, and participants.

4. RESEARCH RESULTS AND DISCUSSIONS

Innovations refer to the creation or introduction of new or significantly improved products, services, processes, or ideas that bring about positive change or advancements. Innovations can be driven by technological advancements, shifts in consumer preferences, competitive pressures, or the application of new knowledge and ideas.

In many studies (Kunapatarawong and Martínez-Ros, 2016; Naruetharadhol et al., 2021) the term eco-innovation has been used synonymously with green innovation and environmental innovation. Eco-innovations are innovations that contribute to sustainable development by reducing environmental impacts, enhancing resource efficiency, or addressing ecological challenges. These innovations can take various forms and often focus on minimizing the negative effects of human activities on the environment while promoting economic and social benefits (Naruetharadhol et al., 2021).

Innovation diffusion refers to the process by which new innovations, ideas, products, or practices spread and become adopted across different segments of society, organizations, or markets. This means that the diffusion of innovation is the spread of an innovation that has already been mastered and implemented in new conditions.

Thus, the diffusion of innovations will be understood as a communication process by which an innovation that has already found its positive test in one business entity is transferred on a commercial basis during a certain time period for development to other subjects or other participants of the social system (e.g. business entities), which operate in other conditions or places. That is, the eco-innovation diffusion as a process in green management practices is characterized by four interrelated elements:

- the essence of eco-innovation – an concept, practical activity, or object that is perceived as something new by an individual or another adapting entity;
- means of communication – methods and instruments used to transmit messages between individuals;
- implementation time – the speed of eco-innovation dissemination and adaptation in the social system;
- participants of the social system – an interconnected network (government / business entities / individuals) engaged in eco-innovation diffusion process.

Eco-innovations aim to promote greening (ecologization). This process should be directed toward the goals outlined in Figure 2.

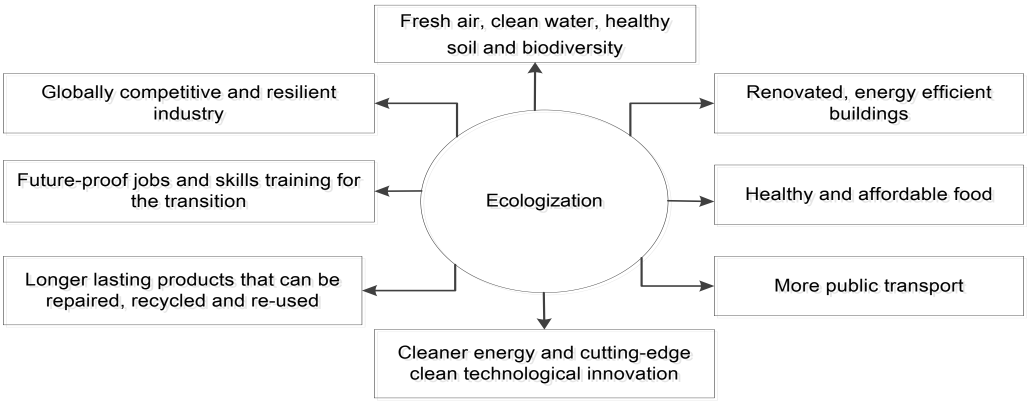

FIGURE 2 – LANDMARKS OF ECOLOGIZATION
Source: own processing based on (European Green Deal, 2022).

Ecologization includes ecosystem protection, resource efficiency, sustainable agriculture and GHG reduction, waste reduction and management, emissions control, sustainable product design, renewable energy integration, green supply chain management, etc. But still the proportion of countries, including those that are highly developed, actively implementing eco-innovations, remains relatively small.

In the global comparison of the Slovak Republic with the world based on the Global Innovation Index, which represents the ranking of world economies based on innovation opportunities, which consists of approximately 80 indicators grouped into inputs and outputs of innovation and covers multidimensional aspects of innovation, Slovakia in 2022 places 46th and in 2023 45th among 132 countries of the world (Table 3).

TABLE 3 – SLOVAK REPUBLIC'S PLACE IN THE GLOBAL INNOVATION INDEX

Years	Global Innovation Index	Innovation inputs	Innovation outputs
2018	36	39	36
2019	37	42	33
2020	39	43	34
2021	37	42	35
2022	46	54	45
2023	45	51	45

Source: own processing based on (Global Innovation Index, 2018-2023).

The strengths and weaknesses of the Slovak Republic's innovation activity are highlighted in Table 4.

TABLE 4 – STRONG AND WEAK POINTS OF THE SLOVAK REPUBLIC'S INNOVATION ACTIVITY

Strengths	Rank	Weaknesses	Rank
High-tech manufacturing, %	3	FDI net inflows, % GDP	109
ISO 14001 environment/bn PPP$ GDP	7	Policies for doing business	109
Creative goods exports, % total trade	8	University-industry R&D collaboration	101
ISO 9001 quality/bn PPP$ GDP	9	VC received, value, % GDP	83
Production and export complexity	13	VC recipients, deals/bn PPP$ GDP	82
National feature films/mn pop. 15-69	15	Entrepreneurship policies and culture	81
Environmental performance	18	Intangible asset intensity, top 15, %	79
Country-code TLDs/th pop. 15-69	23	Unicorn valuation, % GDP	48
High-tech imports, % total trade	23	Global corporate R&D investors, top 3, mn US$	40
High-tech exports, % total trade	24		

Source: own processing based on (Global Innovation Index, 2023).

TABLE 5 – INDICATORS INCLUDED IN EIS

	Indicator	№	Indicator
1	Framework conditions	3	Innovation activities
1.1	Human resources	3.1	Innovators
1.1.1	New doctorate graduates (in STEM)	3.1.1	SMEs with product innovations
1.1.2	Population aged 25-34 with tertiary education	3.1.2	SMEs with business process innovations
1.1.3	Lifelong learning	3.2	Linkages
1.2	Attractive research systems	3.2.1	Innovative SMEs collaborating with others
1.2.1	International scientific co-publications	3.2.2	Public-private co-publications
1.2.2	Top 10% most cited publications	3.2.3	Job-to-job mobility of Human Resources in Science & Technology
1.2.3	Foreign doctorate students	3.3	Intellectual assets
1.3	Digitalization	3.3.1	PCT patent applications
1.3.1	Broadband penetration	3.3.2	Trademark applications
1.3.2	Individuals who have above basic overall digital skills	3.3.3	Design applications
2	Investments	4	Impacts
2.1	Finance and support	4.1	Employment impacts
2.1.1	R&D expenditure in the public sector	4.1.1	Employment in knowledge-intensive activities
2.1.2	Venture capital expenditures	4.1.2	Employment in innovative enterprises
2.1.3	Direct government funding and government tax support for business R&D	4.2	Sales impacts
2.2	Firm investments	4.2.1	Medium and high-tech product exports
2.2.1	R&D expenditure in the business sector	4.2.2	Knowledge-intensive services exports
2.2.2	Non-R&D innovation expenditures	4.2.3	Sales of product innovations
2.2.3	Innovation expenditures per person employed in innovation-active enterprises	4.3	Environmental sustainability
2.3	Use of information technologies	4.3.1	Resource productivity
2.3.1	Enterprises providing training to develop or upgrade ICT skills of their personnel	4.3.2	Air emissions by fine particulates PM2.5 in Industry
2.3.2	Employed ICT specialists	4.3.3	Development of environment-related technologies

Source: own processing based on (European Innovation Scoreboard, 2023).

Another rating, namely the European Innovation Scoreboard (EIS) (2023) distinguishes between four main types of activities – Framework conditions, Investments, Innovation activities, and Impacts – with 12 innovation dimensions, capturing in total 32 indicators. Each main group includes an equal number of indicators and has an equal weight in the average performance score, or the Summary Innovation Index (SII). Within each group, every indicator has the same weight. Indicators that are included in the measurement framework are presented in Table 5.

According to the results of 2022 and 2023, based on the Summary Innovation Index, the country is grouped into 4 groups (Table 6).

TABLE 6 – GROUPING OF COUNTRIES BY RESULTS OF INNOVATION ACTIVITY IN 2022 AND 2023

Groups	Countries in 2022	Countries in 2023
Group 1 is "Innovation leaders" (countries where performance is above 125% of the EU average)	Belgium, Denmark, Finland, the Netherlands, and Sweden.	Belgium, Denmark, Finland, the Netherlands, and Sweden.
Group 2 is "Strong innovators" (countries with a performance between 100% and 125% of the EU average)	Austria, Cyprus, Estonia, France, Germany, Ireland, and Luxembourg.	Austria, Cyprus, France, Germany, Ireland, and Luxembourg
Group 3 is "Moderate innovators" (countries, where performance is between 70% and 100% of the EU average)	Czech Republic, Greece, Italy, Lithuania, Malta, Portugal, Slovenia, and Spain	Czech Republic, Estonia, Greece, Hungary, Italy, Lithuania, Malta, Portugal, Slovenia, and Spain
Group 4 is "Emerging Innovators" (countries that show a performance level below 70% of the EU average.)	Bulgaria, Croatia, Hungary, Latvia, Poland, Romania, and Slovakia.	Bulgaria, Croatia, Latvia, Poland, Romania, and Slovakia.

Source: own processing based on (European Innovation Scoreboard, 2022, 2023).

If the EU as a whole is taken as 100%, then the difference between the EU and V4 countries and the country that ranks first place in the ranking (Denmark). According to the EIS, the SII in 2023 is presented in Table 7.

TABLE 7 – PERFORMANCE SCORES PER DIMENSION IN 2023
(PERFORMANCE IS MEASURED RELATIVE TO THAT OF THE EU IN 2023)

Indicator	Country					
	EU	Denmark	Czech Republic	Hungary	Poland	Slovak Republic
$X_{1.1}$	100	176,7	82,7	49,3	58,3	91,6
$X_{1.2}$	100	189,5	82,6	55	46,2	51,7
$X_{1.3}$	100	145,6	76,7	77,3	81,1	67,1
$X_{2.1}$	100	111,9	82,1	97	61,2	38,1
$X_{2.2}$	100	114,4	113,2	38	59,3	56
$X_{2.3}$	100	149,8	100,4	80,5	90,3	74,7
$X_{3.1}$	100	117,2	138,2	126,9	41,4	42,3
$X_{3.2}$	100	216,2	94,1	112,3	73,7	49,8
$X_{3.3}$	100	136,9	63,1	46,7	84,2	49,4
$X_{4.1}$	100	107,9	106,1	76,9	50,8	55,9
$X_{4.2}$	100	107,7	103,1	51,7	68,2	101,8
$X_{4.3}$	100	129,3	99	57,2	43,8	95,5

Note: X1.1 – human resources; X1.2 – attractive research systems; X1.3 – digitalization; X2.1 – finance and support; X2.2 – firm investments; X2.3 – information technologies; X3.1 – innovators; X3.2 – linkages; X3.3 – intellectual assets; X4.1 – employment impacts; X4.2 – sales impacts; X4.3 – environmental sustainability.
Source: own processing based on (European Innovation Scoreboard, 2023).

Analysis of the indicators values for the Slovak Republic and comparison with the EU countries values as a whole made it possible to identify strengths and weaknesses of the Slovak Republic innovation activity (Figure 3).

In its turn, the Eco-Innovation Index (EII) is a measure composed of 16 sub-indicators across five thematic spheres: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency outcomes and socio-economic outcomes. The overall score for each EU Member State is determined by the unweighted average of these 16 sub-indicators, which reflects how well each country performs in eco-innovation relative to the EU average, set at 100 (index EU=100). This index is part of the Eco-Innovation Scoreboard.

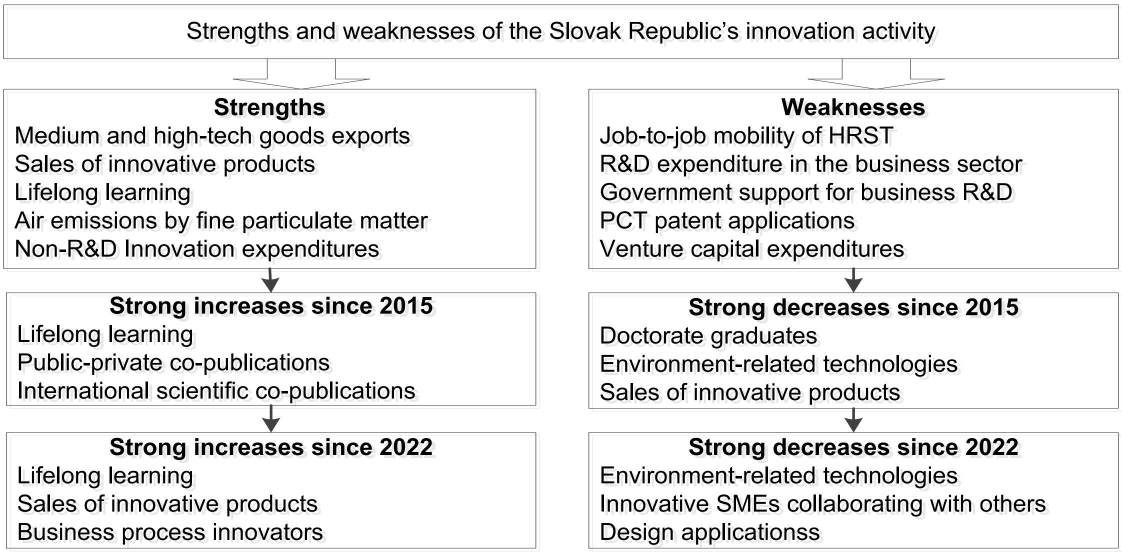

FIGURE 3 – STRENGTHS AND WEAKNESSES OF THE SLOVAK REPUBLIC'S INNOVATION ACTIVITY ACCORDING TO THE SUMMARY INNOVATION INDEX IN 2023

Source: own processing based on (European Innovation Scoreboard, 2023).

The Eco-Innovation Scoreboard (Eco-IS) and the Eco-Innovation Index together provide an overview of eco-innovation performance, which capture various dimensions of eco-innovation through 16 indicators grouped into five categories: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency, and socio-economic outcomes.

Eco-Innovation Index indicators are shown in Table 8.

TABLE 8 – ECO-INNOVATION INDEX INDICATORS

Eco-innovation areas	Indicators	Symbol
1. Eco-innovation inputs	1.1 Governments environmental and energy R&D appropriations and outlays	Z_{11}
	1.2 Total R&D personnel and researchers	Z_{12}
2. Eco-innovation activities	2.1 Number of ISO 14001 certificates	Z_{21}
3. Eco-innovation outputs	3.1 Eco-innovation related patents (per mln population)	Z_{31}
	3.2 Eco-innovation related academic publications (per mln population)	Z_{32}
4. Eco-innovation socio-economic outcomes	4.1 Material productivity	Z_{41}
	4.2 Water productivity (GDP/total fresh water abstraction)	Z_{42}
	4.3 Energy productivity	Z_{43}
	4.4 GHG emissions productivity	Z_{44}
5. Socio-economic outcomes	5.1 Exports of environmental goods and service sector	Z_{51}
	5.2. Employment in environmental protection and resource management activities	Z_{52}
	5.3. Value added in environmental protection and resource management activities.	Z_{53}

Source: own processing based on (Eco-Innovation Index, 2022).

Eco-Innovation Index in 2022 is presented in Table 9.

Regarding the Slovak Republic relative strengths are in eco-innovation activities, and its relative weaknesses are in eco-innovation inputs. The strongest performing eco-innovation indicators are water productivity and the number of ISO 14001 certificates. The weakest performing eco-innovation indicators are eco-innovation related patents and governments environmental and energy R&D appropriations and outlays. Slovakia's performance on CE indicators shows relative strengths in sustainable resource management and relative weaknesses in business operations. The strongest performing CE indicators are the number of EPR schemes and the number of enterprises involved in the repair of computers and personal and household goods. The weakest performing CE indicators are coverage of the circular economy topic in electronic mass media and recycling rate of construction and demolition waste (Eco-Innovation Country Profile, 2022).

TABLE 9 – ECO-INNOVATION INDEX IN 2022

Country	EII	Eco-Innovation Inputs	Eco-Innovation Activities	Eco-Innovation Outputs	Resourse efficiency outcomes	Socio-economic outcomes
European Union	121,47	119,61	101,96	113,12	146,85	104,19
Austria	173,86	141,89	76,45	155,05	127,05	217,25
Belgium	99,78	104,95	37,19	124,6	150,42	37,91
Bulgaria	57,73	28,26	170,67	35,46	17,28	105,14
Croatia	88,81	38,45	171,59	77,3	120,48	76,47
Cyprus	94,65	14,96	151,55	132,11	101,86	104
Czechia	110,98	111,86	233,73	62,38	150,74	104,34
Denmark	167,49	145,35	86,67	221,63	153,53	168,34
Estonia	115,52	45,19	243,26	125,4	31,33	208,88
Finland	178,01	155,07	170,17	213,68	39,12	238,94
France	130,65	149,54	40,88	96,54	161,99	87,08
Germany	141,18	159,83	57,89	162,78	167,08	85,77
Greece	101,59	127,68	85,3	90,27	75,21	101,5
Hungary	81,15	90,62	175,44	47,73	75,18	5,55
Ireland	110,39	61,3	86,26	116,3	206,81	35,88
Italy	129,39	109,69	173,45	77,21	273,54	71,53
Latvia	105,37	47,88	96,15	112,02	135,28	133,34
Lithuania	103,75	49,92	167,78	81,43	137,47	132,89
Luxembourg	179,02	89,65	66,74	184,96	273,54	182,13
Malta	79,76	22,32	39,17	45,34	216,81	39,56
Netherlands	118,78	93,88	71,76	129,57	184,19	81,03
Poland	67,37	45,86	24,88	68,11	84,04	86,73
Portugal	105,69	80,93	33,87	95,27	74,69	126,91
Romania	84,59	31,7	164,56	42,79	40,67	139,64
Slovakia	94,41	51,34	202,36	58,18	144,24	97,3
Slovenia	115,86	122,31	138,16	133,36	102,64	97,07
Spain	116,43	84,47	164,31	70,33	130,98	107,02
Sweden	160,95	135,27	163,53	201,24	117,71	144,15

Source: own processing based on (Eco-Innovation Index, 2022).

To analyze which indicators are most interrelated with AEWR, correlation coefficients were calculated. The correlation matrix is shown in Table 10.

TABLE 10 – THE CORRELATION MATRIX OF DEPENDENCE BETWEEN INDICATORS THAT INFLUENCE THE ECO-INNOVATIONS DEVELOPMENT AND AEWR

	AEWR	FDI	GDP	TAX	GOVEFF	CC	RLAW	RD	ISHIGH	GINI
AEWR	1,00	0,31	0,86	-0,36	0,73	0,80	0,74	0,68	-0,81	-0,85
FDI	0,31	1,00	0,16	-0,04	0,08	0,10	0,06	0,01	0,15	0,13
GDP	0,86	0,16	1,00	0,08	0,84	0,84	0,83	0,64	-0,20	-0,34
TAX	-0,36	-0,04	0,08	1,00	-0,01	-0,04	0,03	0,37	-0,11	-0,05
GOVEFF	0,73	0,08	0,84	-0,01	1,00	0,94	0,95	0,67	-0,24	-0,39
CC	0,80	0,10	0,84	-0,04	0,94	1,00	0,95	0,69	-0,25	-0,40
RLAW	0,74	0,06	0,83	0,03	0,95	0,95	1,00	0,71	-0,30	-0,44
RD	0,68	0,01	0,64	0,37	0,67	0,69	0,71	1,00	-0,43	-0,52
ISHIGH	-0,81	0,15	-0,20	-0,11	-0,24	-0,25	-0,30	-0,43	1,00	0,92
GINI	-0,85	0,13	-0,34	-0,05	-0,39	-0,40	-0,44	-0,52	0,92	1,00

Source: own processing

There is little correlation between total tax and contribution rate (TAX) and AEWR, because countries generally do not use tax incentives for the production and consumption of renewable energy sources. Moreover, an increase in the tax burden will not contribute to the growth of consumption of renewable energy sources. There is also very little correlation between FDI and AEWR, because, perhaps, foreign investments are not directed towards financing alternative energy sources, but for other purposes.

There is significant correlation between GOVEFF, CC, RLAW, RD, and AEWR, which indicates that the higher the efficiency of public administration, control of the corruption level, the level of rule of law in the country and investment in research, the higher the level of production and, as a result, consumption of alternative energy sources, energy-efficient technologies and waste management and recycling implementation.

The higher the ISHIGH and Gini indicators, the higher the level of inequality. These indicators are highly correlated with AEWR, and there is a negative correlation, which is explained by the fact that rising income inequality does not promote the consumption of alternative energy sources, energy-efficient technologies and waste management and recycling implementation (despite the fact that, logically, the richer people are, the more they can invest in eco-innovations).

During innovative diffusion there are various barriers, obstacles to this process. Due to the economic crisis and budget deficits due to lockdowns and war in Ukraine, public and private spending on research and innovation may fall sharply in the coming years. Unfortunately, in today's environment, most threats are no longer local, but global. In such circumstances, the main problem of future economic growth will be not so much the growing need for funds to finance new investments in innovation, as the need to reserve capital to meet the urgent needs that will be caused by risks.

This situation can seriously damage innovation diffusion, while innovation is needed not only to tackle the pandemic but also to address other global challenges, notably climate change, military aggression, and cyberattacks sustainable innovation future.

Barriers to the development, implementation and diffusion of eco-innovations can be, respectively, external and internal to the entity. Among the external barriers were identified:

- bureaucracy, extortion, and corruption, for example, through negative experiences with the nontransparent allocation of EU or other public funds;
- insufficient law enforcement;
- weak infrastructure quality and accessibility, combined with an underdeveloped business support network;
- lack of non-financial support systems;
- limited research and development support, with strong reliance on European investment funds;
- lack of well-established links between the innovation-producing research sector and the industrial sector;
- declining purchasing power of the population due to which they are in no hurry to buy eco-innovative goods and services;
- insufficient interaction of business entities with government, insufficient incentives for businesses to use innovative technologies by the state.

Among the internal barriers were identified:

- lack of own financial resources;
- the shortage of quality labor force, a small number of employees capable of generating innovation;
- low absorption capacity (availability of organizational procedures through which businesses acquire, master and convert available knowledge);

low motivation of employees to develop or diffuse eco-innovations.

The consequences of the existence of barriers to the development, implementation and diffusion of eco-innovations can manifest in the following forms:

- a shift in the planned deadlines for the end of some phase of the innovations life cycle, which will lead to a delay in the process of innovations development, production, implementation, and diffusion, etc.;

- an increase in planned costs associated with the overspending of innovative funds;
- loss of the opportunity to receive income from the implementation of innovation, as potentially effective innovations are not implemented by business entities for various reasons;
- a decrease in planned revenues associated with additional risks that restrain the innovations commercialization in the market;
- inappropriate organizational actions for the implementation of innovation, which complicate the process of finding, implementing and diffusing innovations;
- inefficient business entities' management of changes, inability to deal with resistance to changes;
- lack of business entities innovative potential;
- emergence of unforeseen expenses for the innovations implementation exceeding the planned expenses, etc.

To determine the impact of indicators that influence the eco-innovations development on the AEWR, the regression model was built and tested using the Shapiro-Wilk test, Jarque-Bera test (normality of residuals testing), Breusch-Pagan test (heteroscedasticity testing), Variance inflation factor (multicollinearity testing), Ramsey Regression Equation Specification Error Test test (model specification testing).

The model of the impact of country investment development and economic growth indicators, management level and the willingness of the government to invest in eco-innovation, and the level of income inequality on the consumption of alternative energy sources, energy-efficient technologies, and waste management and recycling implementation (AEWR) has the following form:

$$AEWR = \beta_0 + \beta_1 \times FDI_{it} + \beta_2 \times GDP_{it} + \beta_3 \times TAX_{it} + \beta_4 \times GOVEFF_{it} + \beta_5 \times CC_{it} + \beta_6 \times RLAW_{it} + \beta_7 \times RD_{it} + \beta_8 \times ISHIGH_{it} + \beta_9 \times GINI_{it} + u_{it}, \quad (1)$$

where i denotes the countries considered (i = 1,…,27); t are the years (t = 2013,…,2020); β are model parameters that measure the effects of a change in independent variable in the period t for the i-th country.

The results of the final estimations of the OLS model of the impact of country investment development and economic growth indicators on the AEWR are shown in Table 11.

TABLE 11 – THE RESULTS OF THE MODEL OF THE IMPACT OF INDICATORS ON THE CONSUMPTION OF ALTERNATIVE ENERGY SOURCES, ENERGY-EFFICIENT TECHNOLOGIES, AND WASTE MANAGEMENT AND RECYCLING IMPLEMENTATION

Residuals:					
	Min	1Q	Median	3Q	Max
	-52.460	-9.711	2.129	10.048	47.530
Coefficients:					
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	1.763e+01	1.816e+01	0.971	0.332741	
FDI	5.443e-11	2.038e-11	2.670	0.008179	**
GDP	6.598e-04	8.289e-05	7.960	1.14e-13	***
TAX	-2.591e-01	1.164e-01	-2.226	0.027098	*
GOVEFF	6.294e-01	2.588e-01	2.432	0.015865	*
CC	9.686e-01	2.624e-01	3.691	0.000286	***
RLAW	1.043e+00	3.019e-01	3.454	0.000671	***
RD	2.058e+01	2.298e+00	8.959	< 2e-16	***
ISHIGH	-9.231e+00	1.454e+00	-6.350	1.35e-09	***
GINI	-6.686e+00	9.906e-01	-6.750	1.48e-10	***
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					
Residual standard error: 17.32 on 206 degrees of freedom					
Multiple R-squared: 0.7752, Adjusted R-squared: 0.7653					
F-statistic: 78.91 on 9 and 206 DF, p-value: < 2.2e-16					

Source: own processing

The results showed that the most significant indicators for the consumption of alternative energy sources, energy-efficient technologies, and waste management and recycling implementation are GDP, CC, RLAW, RD, ISHIGH, GINI.

The impact of FDI on eco-innovation may also depend on the country development level. In developing countries, for instance, FDI often serves as a catalyst for the growth of new industrial sectors, facilitating the gradual transition of the labor force from traditional sectors like agriculture.

The level of corruption in the country (CC) leads to a decrease in production, and as a result, consumption of alternative energy sources, energy-efficient technologies, and waste management and recycling implementation, because the state budget is being stolen and funds for the eco-innovations development are being reduced. And vice versa, if corruption control is at a high level, this will lead to an increase in eco-innovations development.

The impact of income inequality on the environment quality and eco-innovations development can have both positive and negative features, which is associated with the following:

1. In rich countries, consumption levels are higher, hence the average human footprint and carbon footprint are also higher. Thus, the average resident of the UK produces 8.5 tons of carbon dioxide per year, and a resident of Canada produces 14.2 tons. At the same time, a resident of India and Indonesia annually produce only 3 and 2.2 tons of carbon dioxide, respectively (Our World in Data. Economic Inequality, 2023).

2. Highly developed countries can invest more in high-tech equipment and a green economy, thereby reducing emissions.

3. Rising income inequality reduces aggregate demand, which reduces emissions, but negatively affects employment and economic growth (poor people cannot buy a lot of energy and other products). The decline of income inequality will increase the middle and high-income groups, reduce the poor, and expand the scale of the middle class; therefore, consumer demand for energy and other carbon intensive products has increased, and carbon emissions will increase.

4. Poor people think less about protecting the environment, because they have other problems, such as how to find a job, how to feed their family, how to pay their mortgage, etc. A person begins to worry about the environment state when his basic needs are closed (when he has a steady income, food, housing, etc.). If a person does not have a permanent job, if he lives below the poverty line, all his thoughts are focused only on how to feed himself and his family. But at the same time in low-income countries, where water, air, and soil are usually critically polluted, residents take environmental problems extremely seriously, because they are directly affected by extreme weather events: droughts, floods, hurricanes, and so on and they simply cannot ignore them.

According to (Climate Inequality Report, 2023) there is a negative correlation between predicted changes in temperature variability and greenhouse gas emissions. On average, countries with comparatively low per capita emissions will experience stronger changes in temperature variability. Those countries that bear the highest responsibility for observed climate change tend to face moderate changes or variability reductions.

5. The inequality leads to discrimination in the level of education and access to quality medical services, and quality food, which reduces labor productivity in the long period and, as a result, GDP. Also, rising income inequality causes social instability, which leads to an increase in crime and social pressure.

6. The rich people have more air travel, and have yachts resulting in significant greenhouse gas emissions. The world's richest 10% were responsible for a half of global greenhouse gas emissions.

7. Rich people can influence national decision-making in favor of their interests (lobbying) and to the detriment of the environment. They receive income from investments in production and are interested in growing consumption. As a result, the environmental state is deteriorating. The wealthiest groups have higher incomes than expenditures, and their savings and investments lead to significant additional environmental impacts. For example, Canada, which has an inequality coefficient of 9.4, emits 14.2 tons of CO_2 per person

per year, while Sweden, which has a lower inequality coefficient (6.2), emits 5.5 tons of carbon dioxide per person (World Inequality Report, 2022).

8. The higher the income inequality level, the more resources are consumed in the country and the more waste is generated. For example, in Sweden, with an inequality coefficient of 6.2, the annual amount of waste per person is 513 kilograms. In Switzerland, with an inequality coefficient of 7, there are already 728 kilograms of waste per person. In Singapore, where the inequality coefficient is 18, the waste rises to 1072 kilograms per person per year (World Inequality Report, 2022).

9. The high level of income inequality leads to biodiversity loss. The proportion of plants and animals that are extinct or endangered is higher in countries with more unequal income distribution (The Sustainable Development Goals Report, 2022).

10. Rising income inequality can drive innovation and economic activities, as a significant portion of income is concentrated in the hands of a few individuals or entities, who can then invest in productive projects both domestically and internationally. Additionally, the wealthier income classes have the resources to innovate and invest in research and development, particularly in areas concerning environmental quality.

Hussain et al. (2022) analyzed the effects of economic development, income inequality, transportation, and environmental expenditures on transport emissions. They found that a 1% increase in income inequality leads to a 32.1% decrease in transport carbon emissions in the long run. Furthermore, a 1% change in income inequality accounts for a 21% reduction in transport carbon emissions, suggesting that resources are being redirected, albeit modestly, towards developing new technologies that address transport-related emissions over a short period. This indicates that income inequality has a more substantial impact on reducing transport carbon emissions in the long run than in the short run.

11. The rich people can afford electric cars, smart homes that require less heating and yachts that run on hydrogen.

The main purpose of building innovative diffusion network structures based on scientific and technical cooperation and the concept of open innovation is the exchange of knowledge between different market participants without taking into account the priority in internal and external interaction. Its main participants are innovators, investors, innovative infrastructure institutes that benefit from network interaction regardless of size and type of activity.

Interaction within the diffusion network is not limited to the exchange of ideas and knowledge between participants. It also involves the search for commercial partners, customers and investors in domestic and foreign markets, not only accelerating the creation and production of innovations, but also intensifying the process of its further implementation, ensuring guaranteed innovative products sales. Socio-economic interaction between the participants in the innovative diffusion network occurs through communication, contacts, persuasion, the formation of the subject's own decisions and their own actions or inactions.

Different diffusion options are possible:

- free nature of diffusion, when the mechanism of imitation or infection operates, when the subject looks at others and copies their behavior;
- purposeful nature of diffusion, when the mechanism of suggestion and persuasion of the recipient by the inductor operates.
- The success of innovations diffusion depends on:
- the technical and cost properties of the eco-innovation, in particular, the presence of competing technologies or products, reasonable cost compared to alternatives, availability, comprehensibility and ease of use, compatibility;
- the potential of the acceptor of innovations, i.e. ability to perceive innovations and carry out innovative activities;

- the presence of a developed network of contacts between the participants of the eco-innovation process, the formation of stable socio-economic ties between them;
- absorptive capacity of the territory (country, region), i.e. the ability to identify, assimilate, and effectively utilize new external information and technologies, which reflects the region's or country's capability to adopt and integrate innovations into its existing systems, enhancing its overall development and competitiveness;
- information provision and security.

To successfully manage the eco-innovation process, it is necessary to decide on a model for eco-innovation network management – linear, cybernetic, matrix, structural, etc. Let us consider the features of the linear and cybernetic models. The linear model for eco-innovation network management reflects the stages of the innovation process, their performers and the results of such a process, but does not show the interaction of innovation entities at different stages of the eco-innovation process (Figure 4).

The linear model is based on the assumption that innovation is applied science. It is "linear" because there is a well-defined set of stages that innovations are assumed to go through. Research (science) comes first, then development, and finally production and marketing (Oliveira, 2014).

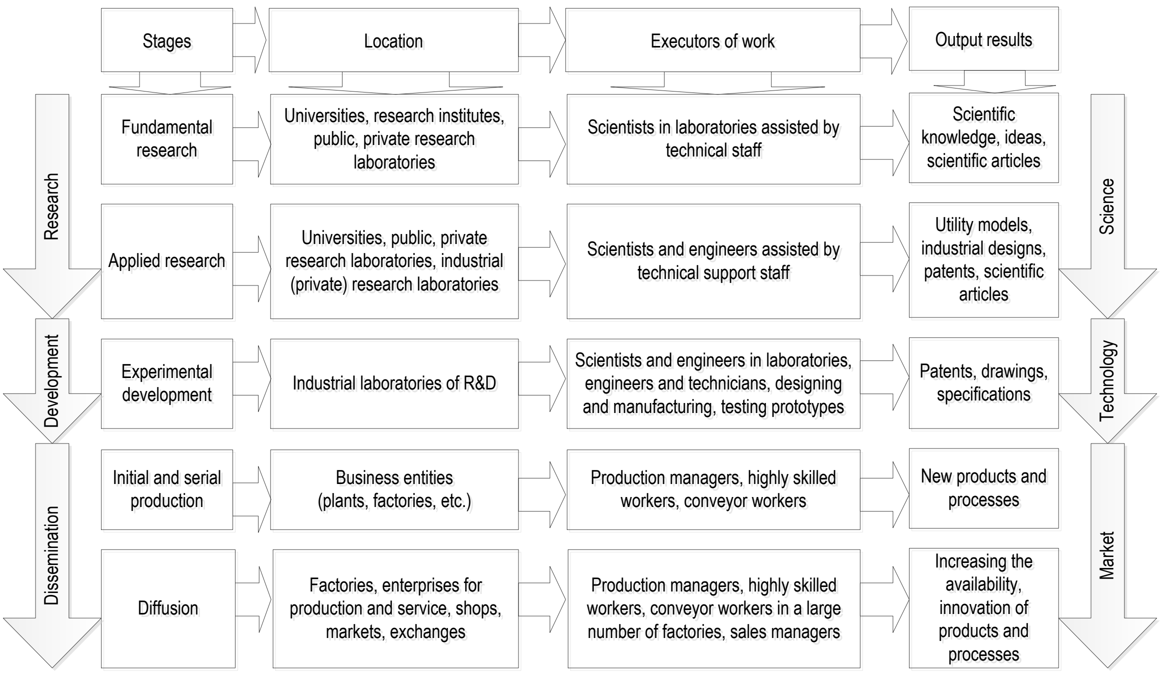

FIGURE 4 – LINEAR MODEL FOR ECO-INNOVATION NETWORK MANAGEMENT
Source: own processing based on (Oliveira, 2014).

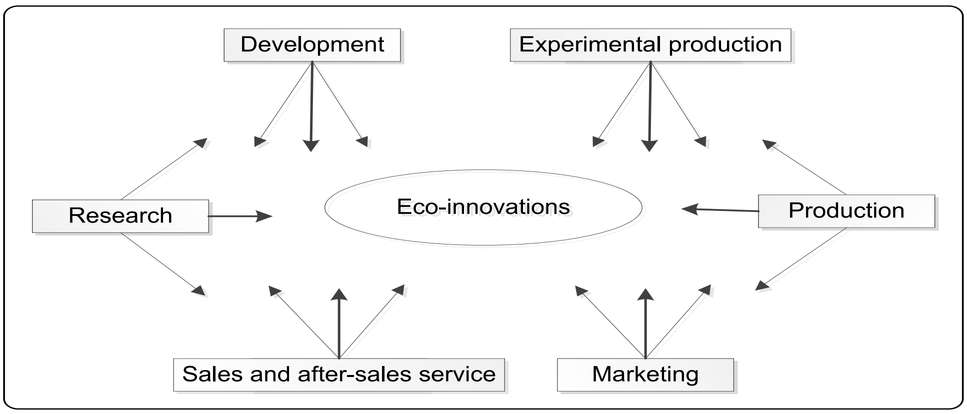

FIGURE 5 – CYBERNETIC MODEL FOR ECO-INNOVATION NETWORK MANAGEMENT
Source: own processing based on (Mirzadeh et al., 2012).

The cybernetic model for eco-innovation network management in an innovative diffuse network allows us to consider the innovation process as a complex system in which process elements form subsystems that are in constant communication and interaction with many feedbacks (Figure 5). The model expresses the continuity of the interaction process.

The influence of the desire of government on the development of eco-innovations remains debatable. Political orientation of the state, particularly, democratic or liberal states have implemented policies that are aimed to environmental preservation, while the republican states aim to support to top percentile of the income distribution, exacerbating income inequality and do not believe in climate change and are not willing to invest in the development of eco-innovations. Also, during the research, the following limitations were identified. Firstly, it was difficult to ensure sample homogeneity, given that a number of indicators were available over time through 2022, and a number of indicators only through 2020. Secondly, Eco-Innovation Index only covers EU countries, so it was not possible to analyze other countries, including non-EU countries.

5. CONCLUSIONS

The dynamics of indicators in the ratings of the Global Innovation Index, the European Innovation Scoreboard, and the Eco-Innovation Index were analyzed. The external and internal barriers to the development, implementation and diffusion of eco-innovations and the consequences of the barriers existence were considered. Among the barriers inherent in many countries, the following are highlighted: the absence of non-financial support mechanism; market entry restrictions; the technical limitations of recycling and material recovery; declining purchasing power of the population due to which they are in no hurry to buy innovative goods and services; underdeveloped network of business support infrastructure, etc.

Also, strengths and weaknesses of the Slovak Republic’s innovation activity were analyzed. The strengths of the Slovak Republic’s innovation activity are medium and high-tech goods exports; sales of innovative products; lifelong learning, air emissions by fine particulate matter; non-R&D Innovation expenditures. The weaknesses are job-to-job mobility of HRST; R&D expenditure in the business sector; government support for business R&D; PCT patent applications; venture capital expenditures.

The correlation coefficients of interdependence between indicators that influence the eco-innovations development and consumption of alternative energy sources, energy-efficient technologies and waste management and recycling implementation were calculated. There is significant correlation between government effectiveness, control of corruption, rule of law, research and development expenditure, and consumption of alternative energy sources, energy-efficient technologies, and waste management and recycling implementation, which indicates that the higher the efficiency of public administration, control of the corruption level, the level of rule of law in the country and investment in research, the higher the level of production and, as a result, consumption of alternative energy sources. There is a negative correlation between income inequality indicators and the consumption of alternative energy sources., which is explained by the fact that rising income inequality does not promote the consumption of alternative energy sources, energy-efficient technologies and waste management and recycling implementation (despite the fact that, logically, the richer people are, the more they can invest in eco-innovations).

The model of the impact of country investment development and economic growth indicators, management level and the willingness of the government to invest in eco-innovation, and the level of income inequality on the consumption of alternative energy sources, energy-efficient technologies, and waste management and recycling implementation was built. The results showed that the most significant indicators for the consumption of alternative energy sources, energy-efficient technologies, and waste management and recycling implementation are GDP per capita, control of corruption, rule of law, research and development expenditure, income share held by highest 10%, and Gini index.

The linear and cybernetic models for eco-innovation network management were considered. The effective eco-innovation networking implies that the relationship between the participants is established and stable, along with the formal close informal relationship, all participants respect each other's interests, interested in obtaining a common synergy effect. Between them, there are different types of relationships, the main of which are economic (in the general sense – the transfer of eco-innovation); legal (registration, protection, and transfer of intellectual property); administrative (control over financing and execution of orders); technological (R&D cooperation and creation of R&D alliances, implementation of eco-innovative goods and technologies); social (professional communities, interactions with universities, relations within the teams involved in the innovation process); informational (perform a multifunctional role, including the fight against misinformation and disinformation).

Within the further research framework it is planned to analyze linkages between eco-innovations and ecological footprints (CO2 footprint), possibilities of implementation climate-smart agriculture and green finance utilization in the agricultural sector, and build models of companies' behavior during eco-innovation projects at different stages of innovation process in global challenges conditions.

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