*Corresponding Author's Email: ceres.matej@gmail.com
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Eco-Innovation Index in Slovakia and EU Countries: Progress and Future Perspectives

Dominika Čeryová, Zuzana Kapsdorferová, and Matej Čereš*

Institute of Economics and Management, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Slovakia

Abstract

Eco-innovation encompasses a broad spectrum of activities aimed at reducing environmental impact and improving resource efficiency, and it plays a crucial role in supporting sustainability. This paper analyzes the development of the Eco-Innovation Index between 2015 and 2024, focusing on countries that ranked among the leaders during this period and those with values below the EU-27 benchmark-based level. The results show a gradual improvement in eco-innovation performance in Slovakia, although there is still considerable room for progress compared with the leading EU countries. One section is devoted to the development of Slovakia's Eco-Innovation Index in comparison with the EU-27 index value and examines the five basic dimensions of this index: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency outcomes, and socio-economic outcomes. The assessment reveals significant differences between Slovakia and the EU-27 performance level, with Slovakia remaining substantially below the current EU-27 index value in several dimensions. The final part of the paper focuses on the food industry in Slovakia, which is an important sector of the national economy and shows increasing relevance for eco-innovation development. Key future trends in the Slovak food industry in the context of eco-innovation include next-generation consumer influence, technological evolution, sustainability achievement, and economic impact. The paper provides an overview of the current state and future perspectives of eco-innovation and identifies areas with potential for further improvement and growth.

Keywords: challenges, development, food industry, sustainability, trends, environmental impact

1. Introduction

Eco-innovation plays a crucial role in promoting sustainability. It encompasses a broad spectrum of activities; all aimed at reducing environmental impact and promoting resource efficiency. Adoption of eco-innovations leads to significant benefits (Zhu et al., 2023; Kráľ & Jánošková, 2021). Organizations that embrace eco-innovation are often more agile and better able to adapt to shifting consumer preferences toward environmentally friendly options (Khanna et al., 2022). Furthermore, eco-innovation is closely intertwined with circular economy principles, reflecting a transformative approach that focuses on waste reduction and resource maximization. This synergy ties economic incentives directly to sustainable practices. However, the adoption of eco-innovation is also heavily influenced by external factors, particularly institutional pressures and regulatory frameworks. Regulatory policies can stimulate eco-innovation by providing structured environments that encourage firms to innovate sustainably. Well-designed regulatory models can foster conditions that incentivize companies to invest in eco-innovative practices, leading to improved compliance and operational efficiency (Pichlak & Szromek, 2022; Sun et al., 2022; Zhidebekkyzy et al., 2024). In addition, the growing demand for accountability and transparency in environmental practices has led many organizations to adopt eco-innovative frameworks, not only to meet regulatory requirements but also to fulfill corporate social responsibilities (Geng et al., 2021; Li et al., 2024). Despite the advantages, barriers to eco-innovation exist and must be carefully addressed to ensure its successful adoption. These barriers, such as financial constraints and lack of knowledge, can hinder the widespread implementation of sustainable practices within firms. Identifying and overcoming these obstacles is critical for fostering a climate that supports eco-innovation (Dugonski & Tumelero, 2021; Antončič et al., 2024). Numerous studies have highlighted the challenges faced by organizations, which can impede progress toward sustainability and eco-innovation (Carchano et al., 2023; Bucea-Manea-Ţoniş et al., 2021). Slovakia, while facing significant barriers such as limited financial resources and a preference for adopting existing technologies rather than developing innovations in-house, is making progress in its eco-innovation efforts (Loučanová & Nosáľová, 2020). One key tool used to assess eco-innovation performance within Slovakia and across the EU is the Eco-Innovation Index (EII). This index offers a comprehensive mechanism for evaluating eco-innovation across five domains: inputs, activities, outputs, resource efficiency, and socio-economic outcomes. By analysing these indicators, Slovakia can identify its strengths and weaknesses in eco-innovation and establish benchmarks that align with EU sustainability goals, ultimately helping to inform policy and investment decisions in environmental technologies (Lesáková & Laco, 2020; Malega et al., 2021). The index is standardized relative to the EU-27 benchmark in the base year 2014, where EU-27 = 100. It allows for cross-country comparison over time, according to the official Eco-Innovation Scoreboard methodology (European Commission, 2024a, 2024b; Eco-Innovation Observatory, 2010). In addition to recent academic studies, the analysis is grounded in the official Eco-Innovation Scoreboard reports and methodology documents published by the European Commission, which provide the main framework for cross-country comparison of eco-innovation performance. The Eco-Innovation Index is also instrumental in highlighting regional disparities, as countries with different levels of innovation culture and government support exhibit varying eco-innovation scores (Constantin et al., 2023; Mačiulytė-Šniukienė & Sekhniashvili, 2021). In the Central and Eastern European context, previous studies indicate that eco-innovation performance is closely linked to the level of R&D support, innovation financing, cooperation between research institutions and enterprises, and the ability to transform eco-innovation inputs into outputs and outcomes. In Slovakia, these issues are particularly relevant, as existing studies point to weaknesses in innovation funding, insufficient links between R&D and business practice, and lower eco-innovation performance compared with leading EU countries (Lesáková & Laco, 2020; Loučanová & Nosáľová, 2020; Malega et al., 2021). Eco-innovations have become a clear target of EU policy strategies. Consequently, measuring eco-innovation performance at the country level has become crucial to detect eco-innovation patterns and to design eco-innovation policy implementation. Slovak policymakers must create an environment that encourages innovation, utilizing the insights provided by the Eco-Innovation Index to implement supportive frameworks and policies (Brogi & Menichini, 2021). The index not only offers valuable data on the drivers and barriers of eco-innovation but also guides decision-makers in focusing resources on areas where the potential for improvement is greatest. By doing so, Slovakia can enhance its competitive position within the EU and contribute to broader sustainability goals (Peyravi et al., 2024; Łozowicka, 2020). Although the Eco-Innovation Index (EII) provides a comprehensive benchmarking tool, it is subject to several methodological limitations. As a composite index, it aggregates heterogeneous indicators, which may obscure structural differences between economies. Furthermore, cross-country comparability may be affected by differences in national statistical systems, data availability, and economic structures. In addition, the EII does not fully capture qualitative dimensions of innovation ecosystems, such as governance quality, policy coherence, entrepreneurial culture, and ecosystem dynamics. These aspects often evolve over time and are associated with significant time lags between policy implementation and observable outcomes. Consequently, reliance on a single aggregate score may oversimplify the complexity of eco-innovation performance. These limitations are consistent with previous studies, which emphasize that qualitative and systemic aspects of innovation are insufficiently reflected in composite and output-oriented indicators (Haller et al., 2023). Therefore, the EII should be interpreted with caution and preferably complemented by qualitative or country-specific analyses. Eco-innovation in the food industry is another key area where sustainability and competitiveness intersect. Innovations in this sector, such as improvements in food quality and safety through sustainable practices, have the potential to enhance both environmental and economic outcomes. For example, the adoption of innovative agricultural practices can lead to higher product quality, which, in turn, increases competitiveness in both local and international markets (Dimitrijević et al., 2023). Furthermore, traceability innovations in food supply chains, particularly those involving digital technologies, play a crucial role in ensuring food safety and reducing waste (Kumar et al., 2022). By enhancing transparency and accountability, these innovations also contribute to building resilience in the food supply chain. However, barriers to eco-innovation in the food sector remain, particularly in areas such as packaging and waste reduction. Addressing these barriers requires collaboration across the entire supply chain. As research by Simms et al. (2019) shows, the integration of eco-innovation practices in the agri-food supply chain can reduce environmental impacts and improve sustainability. The promotion of cooperation among stakeholders is key to overcoming these challenges and driving the successful adoption of eco-innovative practices (Rabadán et al., 2020). Additionally, advancements in food packaging, such as the development of sustainable and bio-based materials, contribute significantly to the sector's eco-innovation efforts (Tiekstra et al., 2021; Versino et al., 2023). The purpose of this paper is to analyse the development of the Eco-Innovation Index in EU countries during the period 2015–2024, to compare Slovakia's performance with the EU-27 value and to examine the role and future prospects of eco-innovation in the Slovak food industry. The paper contributes to the existing literature by combining a long-term comparative analysis of eco-innovation performance with a sectoral focus on the food industry, which represents a key component of the Slovak economy. To balance the literature, the study is also grounded in foundational work on eco-innovation measurement and in recent Central and Eastern European evidence. The Measuring Eco-Innovation (MEI) project provides an important conceptual basis for eco-innovation indicators, as it clarified the concept of eco-innovation, developed a typology, and proposed possible approaches to measurement (Kemp & Pearson, 2007). In addition, the Eco-Innovation Scoreboard is related to the broader European scoreboard tradition, particularly the European Innovation Scoreboard, which supports comparative assessment of national innovation systems, identification of strengths and weaknesses, and evidence-based policy design (Hollanders, 2023; European Commission, 2025). Recent CEE research further shows the relevance of analysing Slovakia together with structurally similar countries, especially the Czech Republic and Poland, because these countries share comparable transformation backgrounds and challenges in converting eco-innovation inputs and activities into outputs and outcomes (Domaracká et al., 2025).

2. Methods

The object of this paper is the Eco-Innovation Index and its development across EU countries, with a particular focus on Slovakia. The study uses publicly available data. The main dataset consisted of annual Eco-Innovation Index values and dimension-level scores for the period 2015–2024. These data were obtained from the official Eco-Innovation Scoreboard and Eco-Innovation Index materials published by the European Commission. The official Eco-Innovation Index report and related Eco-Innovation Scoreboard materials were used as the primary data and methodological sources (European Commission, 2024a, 2024b). The Eco-Innovation Observatory methodological report was also considered as a foundational source explaining the conceptual and measurement basis of eco-innovation (Eco-Innovation Observatory, 2010). Where relevant, the underlying indicators are based on Eurostat and other official data providers, as specified in the official methodology. The Eco-Innovation Index is used in this study as a relative composite indicator of eco-innovation performance. In the current Eco-Innovation Scoreboard framework, it consists of 12 indicators grouped into five thematic areas: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency outcomes, and socio-economic outcomes. The value 100 represents the EU-27 benchmark in the base year 2014. Therefore, values above 100 indicate performance above this reference level, while values below 100 indicate performance below it. Consequently, the EU-27 index value in later years may exceed 100 if overall EU-27 eco-innovation performance improves compared with the 2014 benchmark. When Slovakia is compared with the EU-27 index value in a given year, the comparison refers to Slovakia's position relative to the current EU-27 performance level in that year. The analysis reflects the methodological revisions of the Eco-Innovation Scoreboard. Following the 2021 evaluation, selected indicators were excluded from the calculation of the index from 2022 onwards in order to streamline the framework and increase the accuracy of the index. These revisions affect the comparability of index values across the observed period, particularly between the periods before and after 2022. Changes in index values therefore reflect not only developments in eco-innovation performance, but also updates in the underlying indicators, data availability, statistical revisions, and time lags in official data reporting.

The paper addresses the following research questions:

RQ1: How did the Eco-Innovation Index develop in EU countries between 2015 and 2024, and which countries consistently performed as eco-innovation leaders or laggards?
RQ2: How did Slovakia's Eco-Innovation Index develop in comparison with the EU-27 value during the same period?
RQ3: Which dimensions of the Eco-Innovation Index explain Slovakia's position relative to the EU-27 value, and which dimensions represent its main strengths and weaknesses?
RQ4: What are the main future perspectives for eco-innovation development in the Slovak food industry?

In this study, progress is understood as a positive change in the Eco-Innovation Index and its five dimensions over time, measured through year-on-year changes, overall percentage change between 2015 and 2024, and comparison with the EU-27 index value. Future perspectives refer to possible directions for the further development of eco-innovation in the Slovak food industry, based on observed trends and available literature. Data processing and analysis were performed in Microsoft Excel. The analytical procedure included the extraction of annual Eco-Innovation Index values and dimension-level scores, calculation of year-on-year percentage changes, calculation of the overall percentage change between 2015 and 2024, and descriptive statistical measures, including average, minimum, maximum, and standard deviation. The analysis covers the period 2015–2024 and includes EU Member States, with a detailed focus on Slovakia. The results are presented using tables and graphical visualisations to illustrate trends and differences in the development of the Eco-Innovation Index and its dimensions over time. To extend the descriptive analysis, a simple trend and convergence analysis was applied. Linear time trends were estimated for Slovakia and the EU-27 using ordinary least squares regression, where the annual Eco-Innovation Index value was regressed on time for the period 2015–2024. The time variable was coded from 1 to 10, corresponding to the years 2015–2024. The regression coefficient indicates the average annual change in the index value, while R^2 expresses the proportion of variation in the index explained by the linear time trend. Statistical significance of the trend was assessed using the p-value of the regression coefficient. Convergence was assessed through the performance gap between the EU-27 and Slovakia, calculated as the difference between the EU-27 index value and the Slovak index value in each year. A reduction in this gap indicates convergence of Slovakia towards the EU-27 performance level, while an increase indicates divergence. Due to the limited number of annual observations, the trend and convergence results are interpreted as an indicative inferential extension of the descriptive comparison. In addition to the trend and convergence analysis, the five dimensions of the Eco-Innovation Index were assessed through a functional linkage framework. This framework follows the logic of inputs → activities → outputs → outcomes. Eco-innovation inputs represent the R&D-related and research-capacity conditions for eco-innovation. Eco-innovation activities reflect the implementation of environmental and organisational practices, including ISO 14001 certification. Eco-innovation outputs capture measurable knowledge-based results, such as eco-innovation-related patents and academic publications. Resource efficiency outcomes and socio-economic outcomes represent the final effects of eco-innovation in terms of productivity, exports, employment, and value added. For each dimension, the average values for Slovakia and the EU-27 over the period 2015–2024 were calculated. The relative position of Slovakia was expressed as the ratio between the Slovak average and the EU-27 average for each dimension. The change between 2015 and 2024 was also calculated for each Slovak dimension. This approach identifies whether Slovakia's eco-innovation performance is driven mainly by R&D-related inputs, environmental management activities, measurable innovation outputs, or final resource-efficiency and socio-economic outcomes. To strengthen the reliability and robustness of the analysis, the aggregate Eco-Innovation Index was complemented by dimension-level results, year-on-year changes, overall percentage changes, linear trend coefficients, convergence gaps, and the functional linkage framework. This approach reduces reliance on a single composite score and makes it possible to identify dimensions that drive or limit Slovakia's eco-innovation performance. The interpretation also takes into account the methodological limitations of composite indicators. Since the Eco-Innovation Index aggregates heterogeneous indicators into one score, the results may be influenced by indicator selection, weighting and aggregation structure, methodological revisions, data availability, and time lags in statistical reporting. Therefore, the results are interpreted as comparative indicators of eco-innovation performance rather than as a complete evaluation of national eco-innovation systems. Due to the limited availability of sector-specific eco-innovation data for the Slovak food industry, the sectoral part of the study has an exploratory character and does not provide a separate sector-specific Eco-Innovation Index. Instead, it interprets the future perspectives of eco-innovation in the Slovak food industry on the basis of general Eco-Innovation Index trends, available literature, policy context, and selected proxy indicators, including environmental management systems, ISO

14001 certification, resource efficiency, waste reduction, sustainable packaging, and digital traceability.

3. Results

3.1 Eco-Innovation Index

Table 1 shows the development of the Eco-Innovation Index during the period 2015–2024 for countries that were among the leaders in the given period, as well as for countries with values below the current EU-27 index value.

Table 1: Eco-Innovation Index – "Leaders" and "Catching Up" Countries (2015–2024)

Year	Eco-Innovation Leaders	Score	Eco-Innovation Catching Up	Score
2015	Finland	164.4	Bulgaria	30.4
2016	Finland	170.0	Bulgaria	33.2
2017	Finland	166.5	Bulgaria	28.1
2018	Finland	157.2	Bulgaria	36.0
2019	Sweden	164.2	Bulgaria	36.5
2020	Finland	166.1	Bulgaria	40.1
2021	Finland	168.2	Bulgaria	43.1
2022	Finland	178.6	Bulgaria	48.9
2023	Finland	179.4	Bulgaria	53.9
2024	Finland	180.8	Bulgaria	58.8

Source: own processing based on European Commission, 2024a, 2024b; Eco-Innovation Observatory, 2010

In the period 2015–2024, the Nordic countries – Finland, Sweden, and Denmark – dominated the Eco-Innovation Index values. Finland ranked first most frequently, leading the index in nine out of ten years during the observed period. Finland maintained steady growth in its eco-innovation index score. It reached its lowest score in 2018 (157.2), but the trend has been improving since that year. Sweden overtook Finland in 2019, but it returned to the top of the ranking in the next monitored year. Denmark and Sweden exchanged positions with each other, with Denmark achieving the highest values in 2016 and 2024. These results indicate strong and sustained support for eco-innovation in the Nordic countries. In addition to the Nordic countries, Luxembourg and Austria were also regularly ranked among the leading countries, with Austria often ranking 3rd to 5th. Some countries showed below-average values of the Eco-Innovation Index compared to the EU-27 value during the monitored period (the last 5 places were alternately occupied by countries such as Greece, Romania, Malta, Slovakia, Poland, Hungary, and Bulgaria). Bulgaria was in last place throughout the monitored period.

3.1.1 Eco-Innovation Index of Slovakia

Table 2 shows the development of Slovakia's Eco-Innovation Index compared to the EU-27 value.

Table 2: Eco-Innovation Index of Slovakia compared to the EU-27 index value (2015–2024)

Year	Slovakia	Year-on-year change (in %)	EU-27 value	Year-on-year change (in %)
2015	64.0	-	101.9	-
2016	68.5	7.30	104.2	2.26
2017	70.1	2.34	104.0	-0.19
2018	72.0	2.71	107.4	3.27
2019	65.5	-9.03	108.0	0.56
2020	70.9	8.24	109.6	1.48
2021	77.2	8.89	115.0	4.93
2022	80.3	4.20	118.9	3.39
2023	91.0	13.33	123.7	4.40
2024	98.9	8.68	127.5	3.70
Average	75.84		112.02	
Minimum	64.00		101.90	
Maximum	98.90		127.50	
Standard Deviation	11.34		8.84	

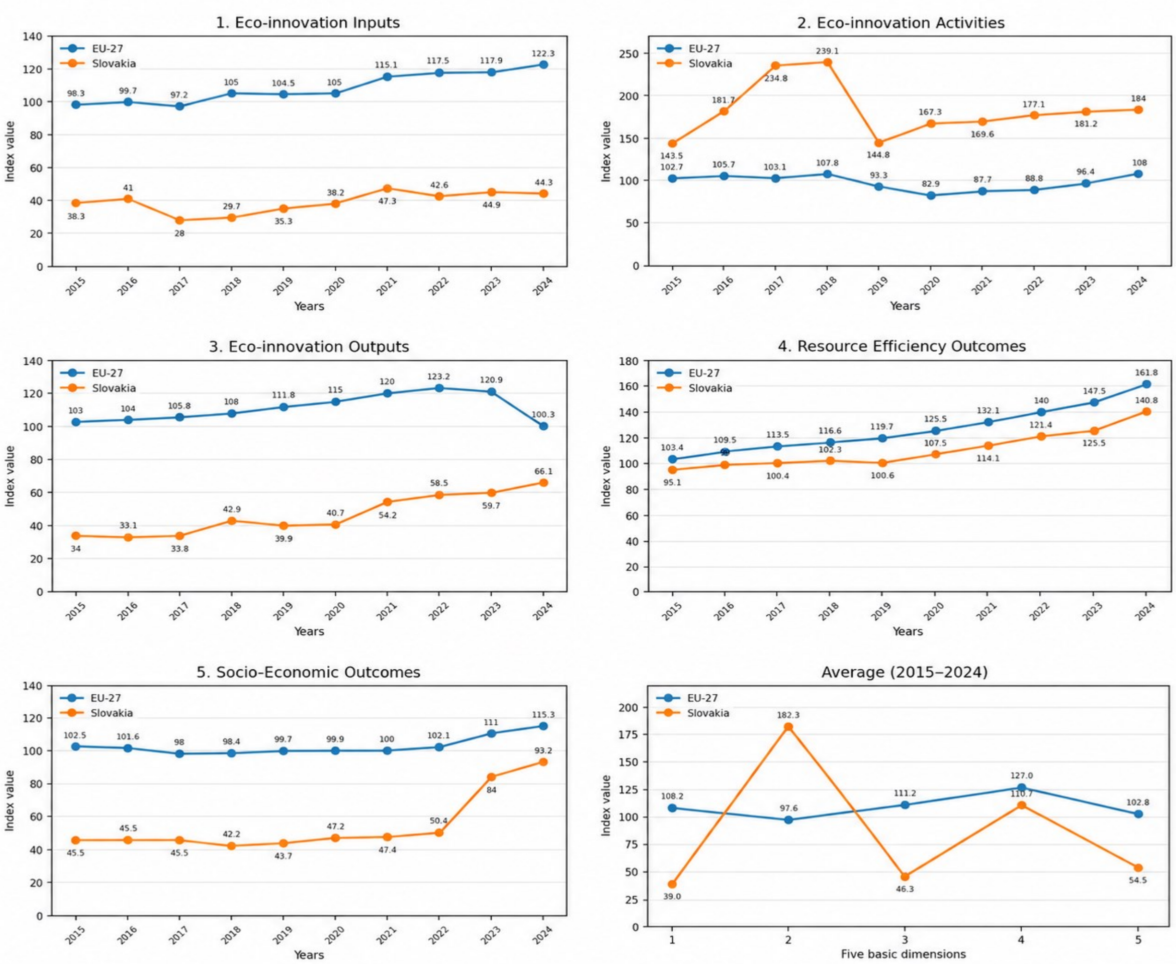
Source: own processing based on European Commission, 2024a, 2024b; Eco-Innovation Observatory, 2010

Note: Year-on-year change was calculated as the percentage difference between the value in the current year and the value in the previous year. The Eco-Innovation Index is expressed relative to the EU-27 benchmark in the base year 2014, where EU-27 = 100. Therefore, EU values in later years may exceed 100. Values above 100 indicate performance above the 2014 EU-27 reference level, while values below 100 indicate performance below this benchmark.

Slovakia experienced an overall increasing trend in the Eco-Innovation Index over the past decade, despite a year-on-year decline between 2018 and 2019. The index increased from 64.0 in 2015 to 98.9 in 2024, representing a 54.5% increase. In 2024, Slovakia almost reached the 2014 EU-27 reference benchmark of 100 points. However, the EU-27 index value increased from 101.9 in 2015 to 127.5 in 2024, representing a 25.1% increase. This shows that, although Slovakia improved at a faster relative pace, it still remained below the current EU-27 performance level in 2024. In terms of year-on-year changes, the largest decrease in Slovakia was recorded in 2019 (-9.03%), while the most significant increase was recorded in 2023 (+13.33%). The EU-27 value shows more stable growth, with the highest year-on-year increase (4.93%) recorded in 2021, likely in response to the COVID-19 pandemic-related stimulus. The trend analysis confirms the positive development of Slovakia's eco-innovation performance. During the period 2015–2024, Slovakia recorded an average annual increase of 3.29 index points, while the EU-27 increased by 2.82 index points per year. The linear trend was statistically significant for both Slovakia ($R^2 = 0.774$; $p = 0.0008$) and the EU-27 ($R^2 = 0.935$; $p < 0.001$). These results show that Slovakia improved at a faster average annual pace than the EU-27, although it started from a considerably lower level. The convergence analysis shows that the performance gap between the EU-27 and Slovakia decreased from 37.9 index points in 2015 to 28.6 index points in 2024. This represents a reduction of 9.3 index points, or approximately 24.5%. The narrowing of the gap indicates partial convergence of Slovakia towards the EU-27 performance level. However, the linear trend in the gap was not statistically significant over the observed period ($p = 0.291$), which indicates that the convergence process was gradual and uneven rather than stable throughout the whole period. Statistical analysis shows that the average index value in Slovakia was 75.84, which is significantly below the EU-27 value (112.02). Slovakia recorded the lowest index value in 2015 (64.0) and the highest in 2024 (98.9). The variability of the index in Slovakia was higher than that of the EU-27 value, as indicated by the standard deviation values of 11.34 and 8.84, respectively. Although Slovakia shows a positive trend in eco-innovation performance and has been growing faster than the EU-27 value in recent years, it still faces challenges such as a lower overall level of eco-innovation and high variability of development. If the recent positive trend continues, Slovakia could gradually reduce the gap with the EU-27 value in the coming years. Conversely, if there is stagnation or decline, the country may fall behind again.

In order to provide a more detailed interpretation of Slovakia's eco-innovation performance, the aggregate Eco-Innovation Index was decomposed into its five dimensions. The values are presented directly in Figure 1 to improve comparability between Slovakia and the EU-27 and to ensure a consistent interpretation of the dimension-level results. This approach makes it possible to identify the areas that contribute most to Slovakia's progress, as well as those that continue to limit its overall performance.

Figure 1: Comparison of the five dimensions of the Eco-Innovation Index in Slovakia and the EU-27, 2015–2024



Source: own processing based on European Commission, 2024a, 2024b; Eco-Innovation Observatory, 2010

Note: All values are index scores expressed relative to the EU-27 benchmark in the base year 2014, where EU-27 = 100.

Figure 1 presents the annual development of the five Eco-Innovation Index dimensions for Slovakia and the EU-27 during the period 2015–2024. The figure includes numerical labels for all values, which improves year-to-year comparability and enables a direct comparison between Slovakia and the EU-27 across all dimensions.

During the period 2015–2024, the five basic dimensions of the Eco-Innovation Index for Slovakia and the EU-27 value recorded different trends (Figure 1). The assessment reveals significant differences between Slovakia and the EU-27 value, with Slovakia remaining considerably below the EU-27 value in several areas.

1. Eco-innovation Inputs: The EU-27 value in this dimension has been stable around the index value of 100.0, with a slight increase since 2018, reaching a value of 122.3 in 2024. On the contrary, Slovakia has experienced large fluctuations – in 2015 the value was 38.3, then it fell to a minimum of 28.0 in 2017 and gradually increased to 44.3 in 2024. Despite the growth, Slovakia remains significantly below the EU-27 value, which indicates insufficient investment in inputs in the field of eco-innovation (government environmental and energy R&D appropriations and outlays, Total R&D personnel and researchers).

2. Eco-innovation Activities: In this area, a significant contrast can be observed between Slovakia and the EU-27 value. While the EU has experienced a slight decline in recent years (from 107.8 in 2018 to 82.9 in 2020, with an increase to 108 in 2024), Slovakia recorded higher values, indicating high activity in the field of eco-innovations, which include, among other things, the number of ISO 14001 certificates.

3. Eco-innovation Outputs: For the EU-27 value, this dimension showed stable growth until 2022 (123.2), after which it decreased to 100.3 in 2024. Slovakia initially had a very low value, but since 2018, there has been a moderate growth, reaching 66.1 in 2024. This development indicates a positive trend in the creation of eco-innovation outputs (which include eco-innovation-related patents and eco-innovation-related academic publications), although Slovakia still lags behind the EU-27 value.

4. Resource Efficiency Outcomes: The EU-27 value shows continuous growth, from 103.4 in 2015 to 161.8 in 2024, which indicates improving resource efficiency. Slovakia recorded lower values, but since 2020, the values have been increasing, indicating a positive development in the efficiency of resource use, such as material productivity, water productivity, energy productivity, and greenhouse gas productivity.

5. Socio-Economic Outcomes: For the EU-27 value, this dimension remained relatively stable, moving around the value of 100.0, until a more significant increase to 115.3 in 2024. Slovakia experienced stagnation in this area in 2015–2017 (45.5), a decrease in 2018 (42.2), and then a slight increase. A more significant increase occurred in 2024, where the value rose to 93.2, indicating a gradual improvement in the socio-economic benefit of eco-innovations (export, employment, and value added).

Table 3: Functional interpretation of Slovakia's Eco-Innovation Index dimensions, 2015–2024

Dimension	Functional interpretation	Slovakia average	EU-27 average	Slovakia as % of EU-27	Slovakia 2015–2024 change
Eco-innovation inputs	R&D resources and research capacities	39.0	108.2	36.0%	+6.0 points; +15.7%
Eco-innovation activities	Environmental management practices, including ISO 14001	182.3	97.6	186.7%	+40.5 points; +28.2%

Eco-innovation outputs	Eco-innovation-related patents and academic publications	46.3	111.2	41.6%	+32.1 points; +94.4%
Resource efficiency outcomes	Material, water, energy and greenhouse gas productivity	110.7	127.0	87.2%	+45.7 points; +48.1%
Socio-economic outcomes	Exports, employment and value added	54.5	102.8	53.0%	+47.7 points; +104.8%

Source: own processing based on European Commission, 2024a, 2024b; Eco-Innovation Observatory, 2010.

Note: Average values are calculated from annual dimension-level index scores presented in Figure 1 for the period 2015–2024. Slovakia as % of EU-27 was calculated as the ratio between the Slovak average and the EU-27 average for each dimension.

The functional interpretation of the five dimensions reveals a structural imbalance in Slovakia's eco-innovation performance. The weakest position was recorded in eco-innovation inputs, where Slovakia reached an average value of 39.0 points in 2015–2024, representing only 36.0% of the EU-27 average. This dimension includes R&D-related resources and research capacities, which indicates that Slovakia's eco-innovation system remains constrained by a relatively weak input base. A similar weakness is visible in eco-innovation outputs, where Slovakia reached an average value of 46.3 points, or 41.6% of the EU-27 average. Although this dimension improved from 34.0 points in 2015 to 66.1 points in 2024, the transformation of R&D inputs into measurable outputs, such as eco-innovation-related patents and academic publications, remains limited.

In contrast, Slovakia performed strongly in eco-innovation activities, with an average value of 182.3 points, representing 186.7% of the EU-27 average. This reflects a relatively strong position in the implementation of environmental and organisational practices, including ISO 14001 certification. However, the high value of eco-innovation activities is not accompanied by equally strong eco-innovation outputs. This indicates that Slovakia is more advanced in adopting environmental management practices than in generating new technological and knowledge-based eco-innovation outputs.

The outcomes dimensions show a mixed but improving pattern. Slovakia reached 110.7 points in resource efficiency outcomes, corresponding to 87.2% of the EU-27 average, and increased from 95.1 points in 2015 to 140.8 points in 2024. This indicates that improvements in environmental practices are gradually reflected in more efficient use of resources. Socio-economic outcomes also improved substantially, from 45.5 points in 2015 to 93.2 points in 2024, although the average Slovak value still represented only 53.0% of the EU-27 average. Overall, the results show that Slovakia's main challenge is not only the adoption of environmental management practices, but especially the strengthening of R&D inputs and the transformation of these inputs and activities into patents, publications, higher value added, and other measurable eco-innovation outputs.

3.2 Slovak Food Industry in the Context of Eco-Innovation

The food industry of Slovakia represents a significant sector of the national economy, characterized by dynamic growth and the increasing implementation of eco-innovations. Eco-innovations in this sector represent a key factor for reducing environmental impact and improving the sustainability of production, while their implementation can contribute to a more efficient use of resources. In the Slovak food industry, eco-innovation is reflected, for example, in the adoption of environmental management practices, including ISO 14001 certification, improvements in resource efficiency, increasing attention to sustainability in production processes, investments in sustainable production technologies, and the gradual adoption of resource-efficient practices. Although Slovakia still lags behind leading EU countries in eco-innovation outputs, the food sector shows potential for further development. In the Slovak food industry, eco-innovation should be understood mainly through practical improvements in resource efficiency, energy savings, water management, waste reduction, sustainable packaging, digital traceability, and the introduction of environmental management systems. These areas are particularly relevant because the food industry is resource-intensive and is strongly affected by changing consumer expectations, environmental regulation, and the need to reduce production losses across the supply chain. In this context, eco-innovation does not only refer to technological innovation, but also to organisational and process changes that help firms reduce environmental impacts while maintaining competitiveness. Due to the limited availability of sector-specific data for Slovakia, this section should be interpreted as an exploratory overview of trends rather than a full empirical sectoral assessment. For this reason, the sectoral part of the paper does not calculate a separate food-industry Eco-Innovation Index. Instead, it interprets the future perspectives of eco-innovation in the Slovak food industry on the basis of general Eco-Innovation Index trends and available literature on agri-food eco-innovation.

In the Slovak context, eco-innovation in the food industry is closely linked to the circular economy, food and bio-waste management, resource efficiency, and environmental management systems. The Slovak circular economy framework identifies the food and bio-waste value chain as one of the priority areas for achieving circularity. This creates an important policy context for eco-innovation in food processing, especially in relation to waste prevention, by-product valorisation, packaging reduction, and more efficient use of energy and water. At the firm level, environmental management systems can be used as a proxy for eco-innovation activities. ISO 14001 certification, for example, indicates that a company has implemented a structured environmental management system and can therefore support improvements in monitoring, compliance, waste reduction, and resource efficiency. The main barriers to eco-innovation in the Slovak food industry include limited investment capacity, high costs of modern environmental technologies, insufficient cooperation between enterprises and research institutions, fragmented support instruments, and limited availability of sector-specific eco-innovation data. These barriers are particularly relevant for small and medium-sized food-processing enterprises, where financial and human resources for innovation are often limited. At the same time, several enablers can support the further development of eco-innovation in the sector. These include EU and national funding schemes, circular economy policies, increasing demand for sustainable food products, pressure to reduce food waste and packaging waste, digital traceability systems, energy-efficiency measures, and the implementation of environmental management systems such as ISO 14001. Based on these sector-specific barriers and enablers, the future development of eco-innovation in the Slovak food industry can be interpreted through four main trend areas: next-generation consumer influence, technological evolution, sustainability achievement, and economic impact. These trends are not isolated. Consumer demand increases pressure for sustainable products and transparent supply chains; technological evolution supports digital traceability, monitoring, and process optimisation; sustainability achievement is reflected in waste reduction, energy savings, water management, and sustainable packaging; and economic impact is connected with cost savings, competitiveness, and value creation from resource-efficient production.

3.2.1 Key Future Trends in the Slovak Food Industry in the Context of Eco-Innovations

Key future trends in the Slovak food industry in the context of eco-innovation include (Figure 2):

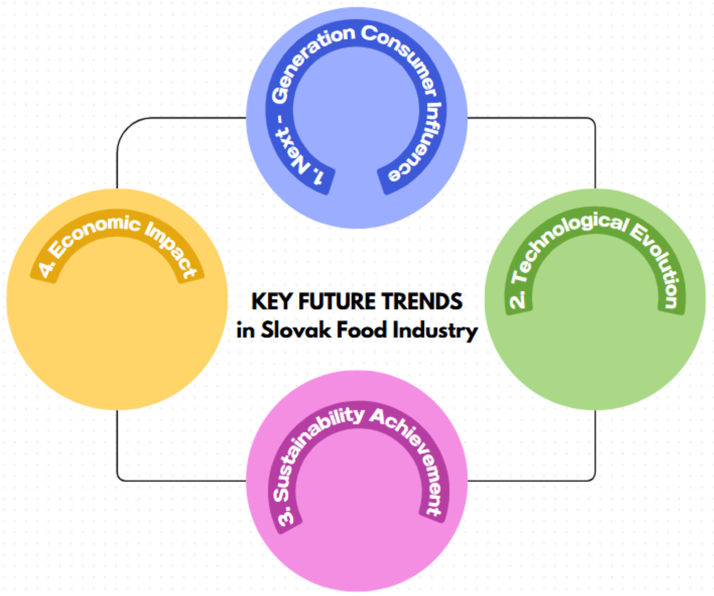


Figure 2: Key future trends in the Slovak food industry

Source: own processing based on the reviewed literature

1. Next-Generation Consumer Influence: Given the growing interest in sustainability, consumer influence is expected to play an important role in shaping the market. Consumers are increasingly demanding products that are environmentally friendly and transparent, which is reflected in their preferences and purchasing decisions. Greater emphasis is also placed on the local origin of products and plant-based alternatives, indicating a shift towards healthier and more sustainable consumption patterns. Consumers, therefore, represent a key driver for businesses, which are required to respond by implementing eco-innovations in their production processes.

2. Technological Evolution: In the field of technology, significant changes are associated with the implementation of advanced technologies such as artificial intelligence and machine learning (AI/ML), which can support production optimization, process monitoring, and efficiency improvements. Technologies contribute to better product traceability, resource management, and quality control. These innovations enhance transparency, improve supply chain management, and help reduce environmental impacts.

3. Sustainability Achievement: The food industry is increasingly oriented towards reducing its negative environmental impact. Businesses focus on lowering their carbon footprint, increasing the use of renewable energy sources, and improving water management and waste reduction practices. Sustainability thus becomes a key element of long-term business strategies in the sector.

4. Economic Impact: Eco-innovation and the transition towards sustainability can have a positive economic impact, particularly in terms of cost efficiency, competitiveness, and overall business performance. Investments in eco-innovations may support revenue growth, improve market position, and contribute to the long-term profitability of companies, especially in the context of growing demand for sustainable products.

The robustness checks support the main interpretation of the results. Slovakia's progress is visible not only in the aggregate Eco-Innovation Index, but also in several complementary measures, including the overall percentage increase, the statistically significant positive trend, the partial narrowing of the gap with the EU-27, and improvements in selected dimension-level outcomes. At the same time, the results confirm that Slovakia's eco-innovation performance remains structurally uneven. The strongest position was observed in eco-innovation activities, while the weakest positions were recorded in eco-innovation inputs and outputs. This confirms that the main challenge is not only the implementation of environmental management practices, but also the strengthening of R&D-related inputs and their transformation into measurable innovation outputs. The interpretation is affected by the limitations of the Eco-Innovation Index as a composite indicator, methodological revisions of the Scoreboard, data lags in selected indicators, and the limited availability of sector-specific data for the Slovak food industry. For this reason, the sectoral discussion is based on available literature, policy context, and proxy indicators, including ISO 14001 certification, resource efficiency, waste reduction, sustainable packaging, and digital traceability.

Conclusion

Eco-innovation is crucial for achieving the European Green Deal objective of transitioning to a carbon-neutral and sustainable economy. In the period 2015–2024, Nordic countries, especially Finland, Sweden, and Denmark, have shown a stable leadership in eco-innovation, with Finland regularly ranking first. In contrast, Eastern European countries, such as Slovakia and Bulgaria, have been at the bottom, with Slovakia making modest progress in recent years. In the period 2020–2024, Slovakia has entered a positive trajectory, with its Eco-Innovation Index increasing from 70.9 to 98.9. This increase is evidence of Slovakia's improved performance in eco-innovation, but the country still remains below the current EU-27 performance level. Slovakia has seen positive developments in eco-innovation, particularly in eco-innovation activities and resource efficiency. However, it still lags significantly behind the EU-27 value in the areas of eco-innovation inputs and outputs, which may limit long-term growth. Nevertheless, increasing resource efficiency and improving socio-economic outcomes indicate a gradual improvement in Slovakia's overall eco-innovation performance. Suggestions and recommendations for the further development of eco-innovations in Slovakia:

- Increase targeted R&D support: Slovakia should strengthen applied research in resource efficiency, circular economy, sustainable packaging, and low-emission technologies. This support should be implemented through targeted grants, applied research calls, and cooperation projects between enterprises, universities, and research institutions. Responsible institutions should include the Ministry of Economy of the Slovak Republic, the Ministry of Education, Research, Development and Youth of the Slovak Republic, the Slovak Innovation and Energy Agency, and the Slovak Research and Development Agency.
- Support startups, SMEs, and digitalisation: Startups and SMEs should be supported through innovation vouchers, co-financing schemes, tax incentives, and advisory services for green and digital technologies. In the food industry, support should focus on digital traceability, process monitoring, energy management systems, and technologies for reducing production losses. Relevant actors include innovation agencies, business support institutions, and sectoral associations.

- Strengthen cooperation with eco-innovation leaders: Slovak companies, public institutions, and research organizations should develop partnerships with leading eco-innovation countries, especially Finland, Sweden, Denmark, Austria, and Luxembourg. Cooperation should focus on joint research projects, technology transfer, pilot solutions, EU-funded programmes, and exchange of good practices in circular economy and resource-efficient production. Such cooperation may help Slovakia improve the transfer of knowledge from research into business practice and accelerate the adoption of proven eco-innovation solutions.
- Stabilize innovation policy and improve coordination: Slovakia should ensure stable, multiannual support for eco-innovation with clear eligibility criteria and regular monitoring of outcomes. Better coordination is needed between national ministries, regional authorities, innovation agencies, research institutions, and business associations. Policy instruments should be evaluated not only according to allocated financial resources, but also according to measurable environmental and innovation outcomes.
- Increase targeted investment in the food industry: In the food industry, eco-innovation support should focus on energy-efficient production lines, water-saving technologies, waste heat recovery, renewable energy, sustainable packaging, by-product valorisation, and digital traceability. Responsible actors should include the Ministry of Agriculture and Rural Development of the Slovak Republic, the Ministry of Economy of the Slovak Republic, the Slovak Innovation and Energy Agency, sectoral associations, and food-processing enterprises. Impacts should be monitored through energy and water consumption per unit of output, food waste reduction, use of recyclable or bio-based packaging, ISO 14001 certification, and cost savings from resource efficiency.

Overall, the proposed measures should be evaluated not only by the amount of financial support provided, but also by measurable improvements in eco-innovation performance, especially in resource efficiency, innovation outputs, and environmental performance of the Slovak food industry. In conclusion, Slovakia is showing positive changes in the field of eco-innovation, but there is still room for improvement compared to EU leaders.

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References

Antončič, J. A., Hojnik, J., Ruzzier, M., Ruzzier, M. K., & Soltwisch, B. (2024). The role of demographic changes and digitalization in eco-innovations and their effects on the growth of companies. Sustainability, 16(14), 6203. https://doi.org/10.3390/su16146203

Brogi, S., & Menichini, T. (2021). Barriers and drivers towards eco-innovation for SMEs: Evidence from the context. Global Journal of Business Economics and Management Current Issues, 11(2), 80–89. https://doi.org/10.18844/gjbem.v11i2.4697

Bucea-Manea-Țoniş, R., Šević, A., Ilić, M. P., Bucea-Manea-Țoniş, R., Šević, N. P., & Mihoreanu, L. (2021). Untapped aspects of innovation and competition within a European resilient circular economy. A dual comparative study. Sustainability, 13(15), 8290. https://doi.org/10.3390/su13158290

Carchano, M., Carrasco, I., & González, Á. (2023). Eco-innovation and environmental performance: Insights from Spanish wine companies. Annals of Public and Cooperative Economics, 95(2), 595–623. https://doi.org/10.1111/apce.12421

Constantin, A., Voica, O., Silvestru, C., Icociu, V., Silvestru, R., & Grecu, A. (2023). The efficiency of resource utilization in EU-28 countries through eco-innovation and digital inclusion. Sustainability, 15(24), 16924. https://doi.org/10.3390/su152416924

Dimitrijević, M., Ristić, L., & Despotović, D. (2023). Agri-food products quality as export competitiveness determinant of the Republic of Serbia. Facta Universitatis Series: Economics and Organization, 117. https://doi.org/10.22190/fueo230412008d

Domaracká, L., Kowal, B., Matušková, S., Čulková, K., & Taušová, M. (2025). Comparative analysis of Eco-Innovation Index—A case study of Slovakia, Czech Republic, and Poland. Sustainability, 17(13), 5797. https://doi.org/10.3390/su17135797

Dugonski, F. C. V., & Tumelero, C. (2021). Barriers and facilitators of technological eco-innovations: A multilevel analysis in a Brazilian cosmetics company. Innovation & Management Review, 19(3), 237–251. https://doi.org/10.1108/inmr-07-2021-0131

Eco-Innovation Observatory. (2010). Methodological report. Eco-Innovation Observatory. https://www.chamberofecocommerce.com/images/EIO_Methodological_Report_2010.pdf

European Commission. (2024a). EU eco-innovation index 2024. Publications Office of the European Union. https://doi.org/10.2777/4878812

European Commission. (2024b). Eco-innovation scoreboard. Green Forum. https://green-forum.ec.europa.eu/eco-innovation_en

European Commission. (2025). European innovation scoreboard 2025. Directorate-General for Research and Innovation. https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en

Geng, D., Lai, K.-h., & Zhu, Q. (2021). Eco-innovation and its role for performance improvement among Chinese small and medium-sized manufacturing enterprises. International Journal of Production Economics, 231, 107869. https://doi.org/10.1016/j.ijpe.2020.107869

Haller, A., Ştefănică, M., Butnaru, G. I., & Butnaru, R. C. (2023). Climate neutrality through economic growth, digitalisation, eco-innovation and renewable energy in European countries. *Kybernetes*, *53*(4), 1250–1280. https://doi.org/10.1108/k-09-2022-1254

Hollanders, H. (2023). A critical assessment of the European Innovation Scoreboard. In F. Gault, A. Arundel, & E. Kraemer-Mbula (Eds.), Handbook of Innovation Indicators and Measurement (2nd ed., pp. 391–412). Edward Elgar Publishing. https://doi.org/10.4337/9781800883024.00032

Kemp, R., & Pearson, P. (2007). Final report MEI project about measuring eco-innovation. UM-MERIT. https://lab.unu-merit.nl/wp-content/uploads/2021/05/Final-report-MEI-project-about-measuring-eco-innovation-1.pdf

Khanna, M., Gusmerotti, N. M., & Frey, M. (2022). The relevance of the circular economy for climate change: An exploration through the theory of change approach. Sustainability, 14(7), 3991. https://doi.org/10.3390/su14073991

Kráľ, P., & Jánošková, K. (2021). Eco-innovation as a tool to support sustainable development and increase the competitiveness of enterprises. SHS Web of Conferences, 129, 05005. https://doi.org/10.1051/shsconf/202112905005

Kumar, M., Raut, R. D., Sharma, M., Choubey, V. K., & Paul, S. K. (2022). Enablers for resilience and pandemic preparedness in food supply chain. Operations Management Research, 15(3–4), 1198–1223. https://doi.org/10.1007/s12063-022-00272-w

Lesáková, Ľ., & Laco, P. (2020). Using eco-innovation index to measure the eco-innovation performance in the global knowledge economy: Evidence from Slovakia. SHS Web of Conferences, 74, 06017. https://doi.org/10.1051/shsconf/20207406017

Li, Y., Tsang, Y. P., Wu, C. H., & Lee, C. K. M. (2024). Exploring eco-innovation barriers to the sustainability transition in cold chain e-fulfilment systems. Journal of Organizational and End User Computing, 36(1), 1–26. https://doi.org/10.4018/joeuc.349583

Loučanová, E., & Nosáľová, M. (2020). Eco-innovation performance in Slovakia: Assessment based on ABC analysis of eco-innovation indicators. BioResources, 15(3), 5355–5365. https://doi.org/10.15376/biores.15.3.5355-5365

Łozowicka, A. (2020). Evaluation of the efficiency of sustainable development policy implementation in selected EU member states using DEA: The ecological dimension. Sustainability, 12(1), 435. https://doi.org/10.3390/su12010435

Mačiulytė-Šniukienė, A., & Sekhniashvili, D. (2021). The eco-innovation impact on economic and environmental performance of EU member states. Business Management and Economics Engineering, 19(02), 212–228. https://doi.org/10.3846/bmee.2021.14497

Malega, P., Majerník, M., Rudy, V., & Daneshjo, N. (2021). Innovation support and eco-innovation in the Slovak Republic in the intentions of sustainable development. Polish Journal of Environmental Studies, 30(4), 3753–3768. https://doi.org/10.15244/pjoes/130910

Peyravi, B., Peleckis, K., Limba, T., & Peleckienė, V. (2024). The circular economy practices in the European Union: Eco-innovation and sustainable development. Sustainability, 16(13), 5473. https://doi.org/10.3390/su16135473

Pichlak, M., & Szromek, A. R. (2022). Linking eco-innovation and circular economy: A conceptual approach. Journal of Open Innovation Technology Market and Complexity, 8(3), 121. https://doi.org/10.3390/joitmc8030121

Rabadán, A., Triguero, Á., & Gonzalez-Moreno, Á. (2020). Cooperation as the secret ingredient in the recipe to foster internal technological eco-innovation in the agri-food industry. International Journal of Environmental Research and Public Health, 17(7), 2588. https://doi.org/10.3390/ijerph17072588

Simms, C., Trott, P., Van Den Hende, E., & Hultink, E. J. (2019). Barriers to the adoption of waste-reducing eco-innovations in the packaged food sector: A study in the UK and the Netherlands. Journal of Cleaner Production, 244, 118792. https://doi.org/10.1016/j.jclepro.2019.118792

Sun, Y., Li, H., Bao, Q., & Lu, Z. (2022). Environmental regulation, sentiment, and eco-innovation: Evidence from China. Frontiers in Environmental Science, 9. https://doi.org/10.3389/fenvs.2021.809452

Tiekstra, S., Dopico-Parada, A., Koivula, H., Lahti, J., & Buntinx, M. (2021). Holistic approach to a successful market implementation of active and intelligent food packaging. Foods, 10(2), 465. https://doi.org/10.3390/foods10020465

Versino, F., Ortega, F., Monroy, Y., Rivero, S., López, O. V., & García, M. A. (2023). Sustainable and bio-based food packaging: A review on past and current design innovations. Foods, 12(5), 1057. https://doi.org/10.3390/foods12051057

Zhidebekkyzy, A., Temerbulatova, Z., Kotásková, A., & Németh, P. (2024). Catalysing responsible production: Evaluating the impact of EPR system on manufacturing enterprises. Journal of International Studies, 17(2), 178–190. https://doi.org/10.14254/2071-8330.2024/17-2/9

Zhu, D., Zhu, H., & Arkorful, V. E. (2023). Institutional pressure and eco-innovation: The moderating role of environmental uncertainty. Science Technology and Society, 29(1), 160–182. https://doi.org/10.1177/09717218231201945