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Mapping Eco-Innovation Dynamics in the EU: A Neural Network Approach

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Abstract: *This paper compares the eco-innovation performance of EU member states based on the eco-innovation index. The comparison was made between two periods, 2013-2017 and 2018-2022, taking into account five groups of indicators of the eco-innovation index. The authors used a software solution grounded on neural networks to determine the correlation, relationship structure, and contribution of the indicators for eco-innovation performances. The research paper seeks to provide novel insights into the complex relationships between different variables influencing eco-innovation, thereby enhancing the understanding of sustainable development pathways in the EU. The structure of the neural network showed the importance of certain indicators that contributed the most to the value of the eco-innovation index. The results showed that in the first period, the best overall performance was achieved in the areas of REO and SCO, while in the second period, in addition to REO and SCO, EA also stood out.*

1. INTRODUCTION

The growing number of environmental problems and the untimely taking of the necessary measures to prevent them, increase the pressure for the transition to a green economy. The aim is to move from traditional production methods to sustainable production, introduce resource-efficient practices, and more efficient processes, reduce the impact of climate change, etc. One of the paths leading to the transition to a circular economy is eco-innovation, which reduces the impact on the environment and encourages more efficient use of resources (Talić et al., 2023). Innovation has been used for a long time to boost the growth and competitiveness of countries, and now they have another role, to improve people's well-being and quality of life (Chaparro-Banegas et al., 2023). Eco-innovation can reduce environmental impacts while simultaneously improving the economic competitiveness of countries (Chaparro-Banegas et al., 2023). The European Commission has prescribed numerous directives related to sustainable development, energy efficiency and environmental protection. The promotion of eco-innovation at the national level is a goal promoted by various EU initiatives (Al-Ajlani et al., 2022). In this sense, it is of great importance to monitor and measure the progress of EU countries in terms of eco-innovation. For this purpose, the Eco-Innovation Index was created. Every year, the member states are ranked based on the eco-innovation index, which will be used in this paper as a starting point for monitoring the dynamics of eco-innovations in the observed countries.

This paper aims to provide novel insights into the complex relationships between different variables influencing eco-innovation by utilizing a neural network model and to compare the performance dynamics of eco-innovation in the EU countries in the observed periods.

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The paper is structured as follows: after the introduction it provides an overview of the previous literature on the determination of eco-innovations. After that, a review of the existing measures of eco-innovation at the macro level was given. The following is a description of the methodology used, a presentation of the results, and their discussion, based on which the conclusions are drawn below.

2. LITERATURE REVIEW

In building a sustainable economy and mitigating the negative effects of economic growth on the environment, eco-innovation plays a crucial role (Hajdukiewicz & Pera, 2023). Increasing pressure on the marketplace and government concerns ensured that eco-innovation development strategy has become a vital part of sustainable development (Bag et al., 2022). For enhancing countries' competitiveness and enabling more sustainable development, eco-innovation is a key strategy that might be implemented at local, national, regional, and international levels. At the level of the economic system, the primary goal of eco-innovation relates to countries' efforts to minimize adverse ecological impacts, maximize the use of renewable resources, and achieve green growth (Terzić, 2023, p. 16). Eco-innovation represents an answer to environmental problems and natural reaction to high resource prices.

Eco-innovation is a relatively new concept, but in conditions where we face problems caused by climate changes, air and water pollution, and loss of biodiversity, it gains importance and becomes the subject of various interest groups. In the last few decades, the concept of eco-innovation has attracted significant attention from researchers, practitioners, and policymakers. The idea of eco-innovation emerged in the 1990s, in the third industrial revolution, and extended during the fourth industrial revolution, as a global concept to support sustainable development on macro and micro levels. Eco-innovation is a multidimensional concept with potentially challenging development and implementation. The nature of eco-innovation is characterized by cognate terms and concepts that are heterogeneous. Some of the most common terms that have been widely used by scholars are green innovation, environmental innovation, and sustainable innovation.

Although exist different definitions of eco-innovation in the literature, the consensus mainly focuses on environmental management and sustainability. One of the earliest definitions of eco-innovation was proposed by Fussler and James (1996). These authors stated that eco-innovation refers to a new product or method that creates value for the company and customers, while substantially lowering negative environmental impacts. According to Rennings (2000), eco-innovation represents all the efforts of relevant actors in introducing, developing and applying new ideas, behaviours, and products, aiming to fulfil certain sustainability goals and mitigate the negative impact on the environment. Some researchers argued that eco-innovation besides organizational, product and process changes in companies, encompass also social, and political changes and changes in environmental regulations in one country (Hellström, 2007). According to OECD (2010), eco-innovation means carrying out marketing activities, processes and organizational structures that foster developing new or existing products and services, while considering environmental impact. On the other hand, eco-innovation is a sustainable tool that advances the performance of environmental actions (Carrillo-Hermosilla et al., 2010), contributing to environmental and economic benefits (Urbaniec, 2015).

By developing and implementing eco-innovation, countries can prevent resource exhaustion and provide favorable environments for obtaining sustainable growth (Jia et al., 2020). Eco-innovation can be comprehensively understood as an entrepreneurial process that includes product design phases and integrated management throughout its entire life cycle and encourages the ecological modernization of the economy and society (Sobczak et al., 2022). Eco-innovation combines innovation and sustainable development and integrates innovation policy and environmental protection policy (Androniceanu & Georgescu, 2023).

3. MEASURING ECO-INNOVATION

Measuring eco-innovation is important for several reasons. Eco-innovation requires continuous improvement, so the use of measurement for their development provides significant feedback and a starting point for their improvement. Measuring eco-innovation is of great importance for policy monitoring and evaluation (Inno4sd, 2019). Based on eco-innovation indicators, policymakers identify, evaluate, and direct the contribution of innovation to pre-set environmental goals. It helps policymakers to analyze and compare trends related to eco-innovations, as well as drivers and limiting factors for their development, which contributes to the creation of more effective policies (OECD, 2010). Measuring eco-innovation helps to assess the progress of countries in different categories of eco-innovation, enables the analysis of drivers of eco-innovation, helps policymakers, and businesses, and generally contributes to the promotion of eco-innovation (OECD, 2010).

Eco-innovations can be classified into four dimensions: product, process, organization, and marketing, therefore, developing an instrument to measure them requires identifying their key performance factors due to adequate measurement of eco-innovation implementation (García-Granero et al., 2020). According to the Green EU report on measuring eco-innovation and green growth (Arundel et al., 2017), measuring eco-innovation and the green economy must include four types of indicators: eco-innovation, eco-policy, environmental indicators, and welfare indicators. Each measurement approach has its advantages and disadvantages and does not comprehensively represent all elements of eco-innovation (OECD, 2010). A systematic approach to measuring eco-innovation is provided by several organizations such as metrics developed by the Eco-Innovation Observatory in Europe, ASEIC and the Clean Technology Group (Inno4sd, 2019).

The Eco-Innovation Observatory developed the Eco-Innovation Index (Eco-IS), a composite index based on 12 indicators grouped into five thematic areas: eco-innovation inputs (EI), eco-innovation activities (EA), eco-innovation outputs (EO), resource efficiency outcomes (REO), and socio-economic outcomes (SCO) (EEA, 2023). The number of indicators within this index has changed over time. It is used to measure and compare the progress of European countries. The Eco-Innovation Index groups countries based on their performance and shows where their weaknesses and strengths are in terms of eco-innovation. Another important EU index is the European Innovation Scoreboard (EIS), an annual index that measures and compares the research and innovation performance of European countries. It includes indicators related to eco-innovation: resource productivity and development of environment-related technologies.

The ASEM Environmental Innovation Index (ASEI) was created with the aim of being an international tool for quantitatively and qualitatively measuring the level and status of eco-innovations. The ACEI index relies on the same definition of eco-innovation used in the European Union. This index is intended primarily to measure eco-innovations at the level of Europe and Asia, to promote eco-innovations and to motivate governments to improve their policies and regulations in this area. It relies on four groups of indicators: eco-innovation capacity, eco-innovation activity, eco-innovation supporting environment, and eco-innovation performance (ASEIC, 2015).

The Global Cleantech Innovation Index (GCII) is a tool that should facilitate governments and policymakers in making decisions and policies related to eco-innovation. It is intended for global application and includes countries from different parts of the world. The scope and focus of this index are narrower compared to the previous indices, Eco-IS and ASEI, and its indicators mainly focus on companies. The GCII contains four sub-categories of indicators: general innovation drivers, Cleantech-specific innovation drivers, evidence of emerging Cleantech innovation and evidence of commercialized Cleantech innovation (Cleantech Group & WWF, 2017).

4. METHODOLOGY

The applied methodology in this research is based on the analysis of the eco-innovation performances of the member states of the European Union and the mapping of their potential for improving the eco-innovation sector. The comparison of the achieved performances of the countries of the European Union was carried out by observing the values of the following five sub-indicators of the overall eco-innovation index (European Commission, 2022), taking into account their average values for the period 2013-2017 and the period 2018-2022:

- Eco-innovation inputs (EI) - Eco-innovation inputs comprise investments (financial or human resources) aiming to trigger eco-innovation activities.
- Eco-innovation activities (EA) - Eco-innovation activities include indicators to monitor the scope and scale of eco-innovation activities undertaken by companies. The component focuses on efforts and activities rather than on the actual results of innovation activity.
- Eco-innovation outputs (EO) - Eco-innovation outputs describe the immediate results of eco-innovation activities. Indicators in this component are used to monitor the extent to which knowledge outputs generated by businesses and researchers relate to eco-innovation.
- Resource efficiency outcomes (REO) - Resource efficiency outcomes relate to the wider effects of eco-innovation on improved resource productivity. Eco-innovation can have a twofold positive impact on resource efficiency: it can increase the generated economic value, while at the same time decreasing pressures on the natural environment.
- Socio-economic outcomes (SCO) - Socio-economic outcomes of eco-innovation depict wider effects of eco-innovation activities for society and the economy. This includes changes in employment, turnover, or exports that can be related to broadly understood eco-innovation activities.

Descriptive statistics of the average value of the overall eco-innovation index are shown in Figure 1 to see the fluctuation of its values in the mentioned periods for each member country individually.

Analysis of the dynamics of the movement of sub-indicators of the aforementioned index was carried out using the software package for neural networks Neural Designer - Machine Learning Software (Neural Designer, 2020). The process of modeling the neural network structure for the sub-indicators of the eco-innovation index consists of a cycle of five phases: data exploration, model training, feature engineering, model testing, and deployment. Neural Designer - Machine Learning Software uses innovative algorithms for simulating and optimizing data of the eco-innovation performances, as growing inputs for evaluating the correlation of each input with each output variable (Rađenović et al., 2020). After collecting data on all sub-indicators of the overall eco-innovation index for both observed periods, the Neural Designer-Machine Learning Software recalculates the degree of correlation that exists between the variables (sub-indicators) of the created model. Consequently, it can be seen that in the period 2013-2017, the highest correlation coefficient was between the variable eco-innovation activities and resource efficiency outcomes (0.822). On the other hand, for the observed period 2018-2022. year, the highest correlation coefficient and positive relationship exists between the variables eco-innovation inputs and eco-innovation outputs (0.647), as well as between eco-innovation inputs and socio-economic outcomes (0.602) (Table 1).

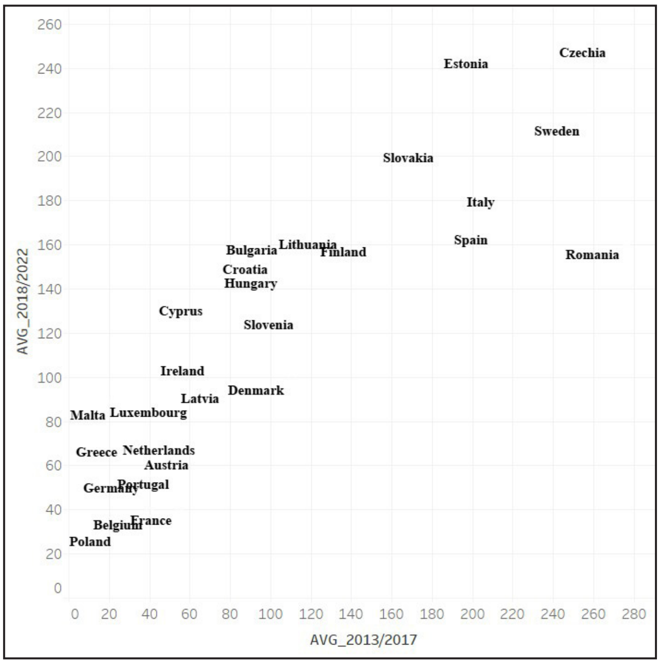

Figure 1. Descriptive statistics with changes in the overall eco-innovation index performances of the EU members for the two analyzed periods

Source: Authors' calculation according to available data

Table 1. Correlation coefficients for the analyzed variables

VAR	2013-2017				
	EI	**EA**	**EO**	**REO**	**SCO**
EI	1	0.172	0.154	0.204	0.207
EA	0.172	1	0.159	**0.822**	0.159
EO	0.159	0.159	1	0.061	-0.195
REO	0.204	**0.822**	0.061	1	0.331
SCO	0.207	0.159	-0.195	0.331	1
VAR	**2018-2022**				
	EI	**EA**	**EO**	**REO**	**SCO**
EI	1	-0.276	**0.647**	0.266	0.267
EA	-0.276	1	-0.212	-0.299	0.212
EO	**0.647**	-0.212	1	0.268	**0.602**
REO	0.266	-0.299	0.268	1	-0.288
SCO	0.267	0.212	**0.602**	-0.288	1

Source: Authors' calculation according to available data

5. RESULTS AND DISCUSSION

Based on the collected data, the Neural Designer created an output value in the form of a neural network architecture for the first analyzed period. Figure 3 shows the network architecture where, after several iterations, the variables resource efficiency and socio-economic outcomes are singled out as dominant in determining the eco-innovation performances of the selected EU countries. A formed neural network consists of scaling and unscaling layered where yellow circles depict scaling neurons, the blue circles' perceptron neurons, and the red circles' unscaling neurons.

In the period 2018-2022, there was a change in the structure of the neural network as well as in the dominance of certain variables on the overall eco-innovation performances. Namely, the variable eco-innovation activities are included in the model, which indicates the fact that countries have taken certain steps in developing awareness of eco-innovation.

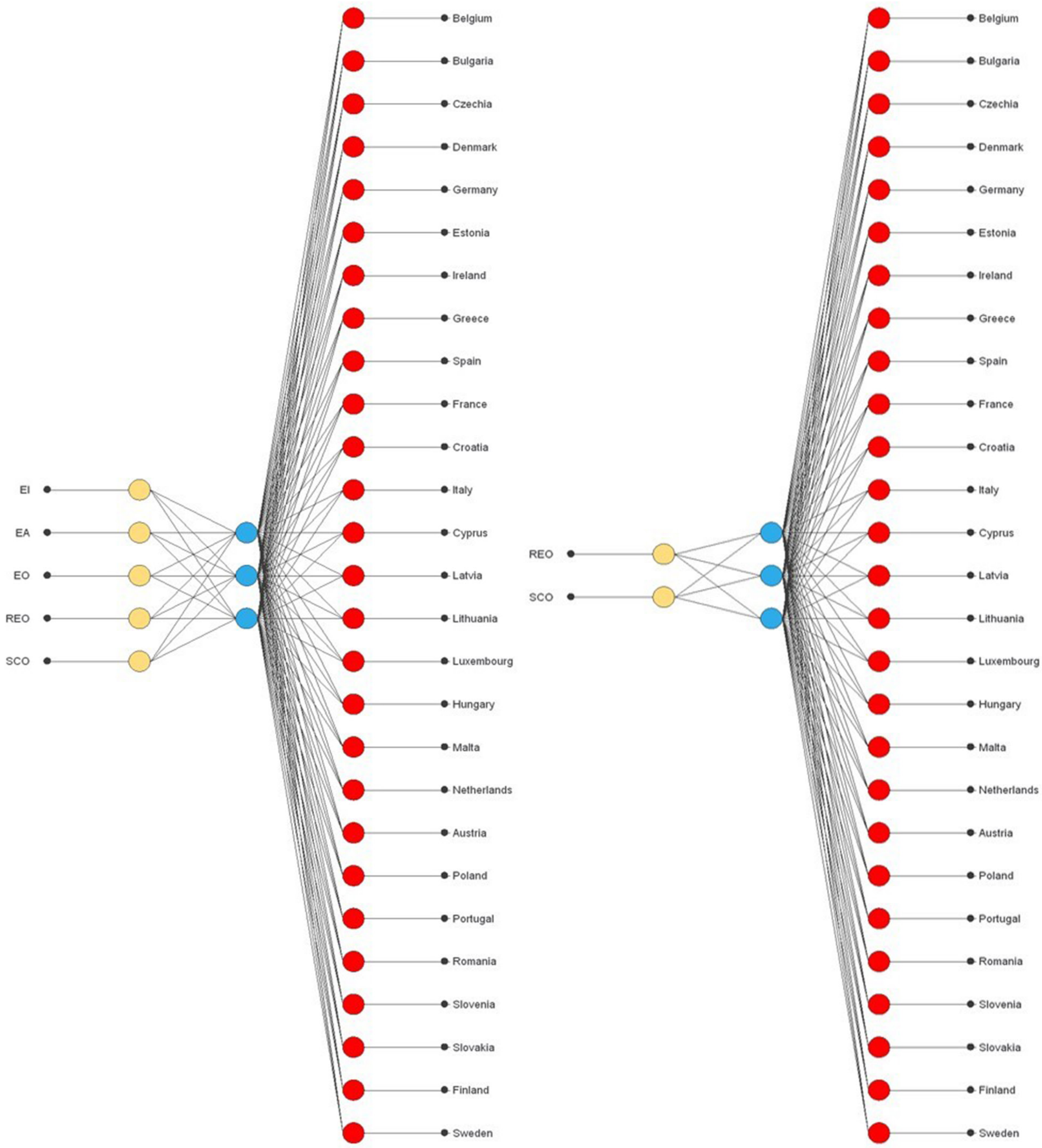

Figure 2. Neural network architecture for the eco-innovation performances of the EU members 2013-2017

Source: Authors' calculation according to available data

The phase of testing the correlation of each input with each output variable in each iteration of the algorithm by gradient information shows the number of training and selection errors (Figure 2). In this type of training, the Quasi-Newton method is used which uses the Hessian of the loss function, a matrix of second derivatives, to calculate the learning direction (Song, 2018).

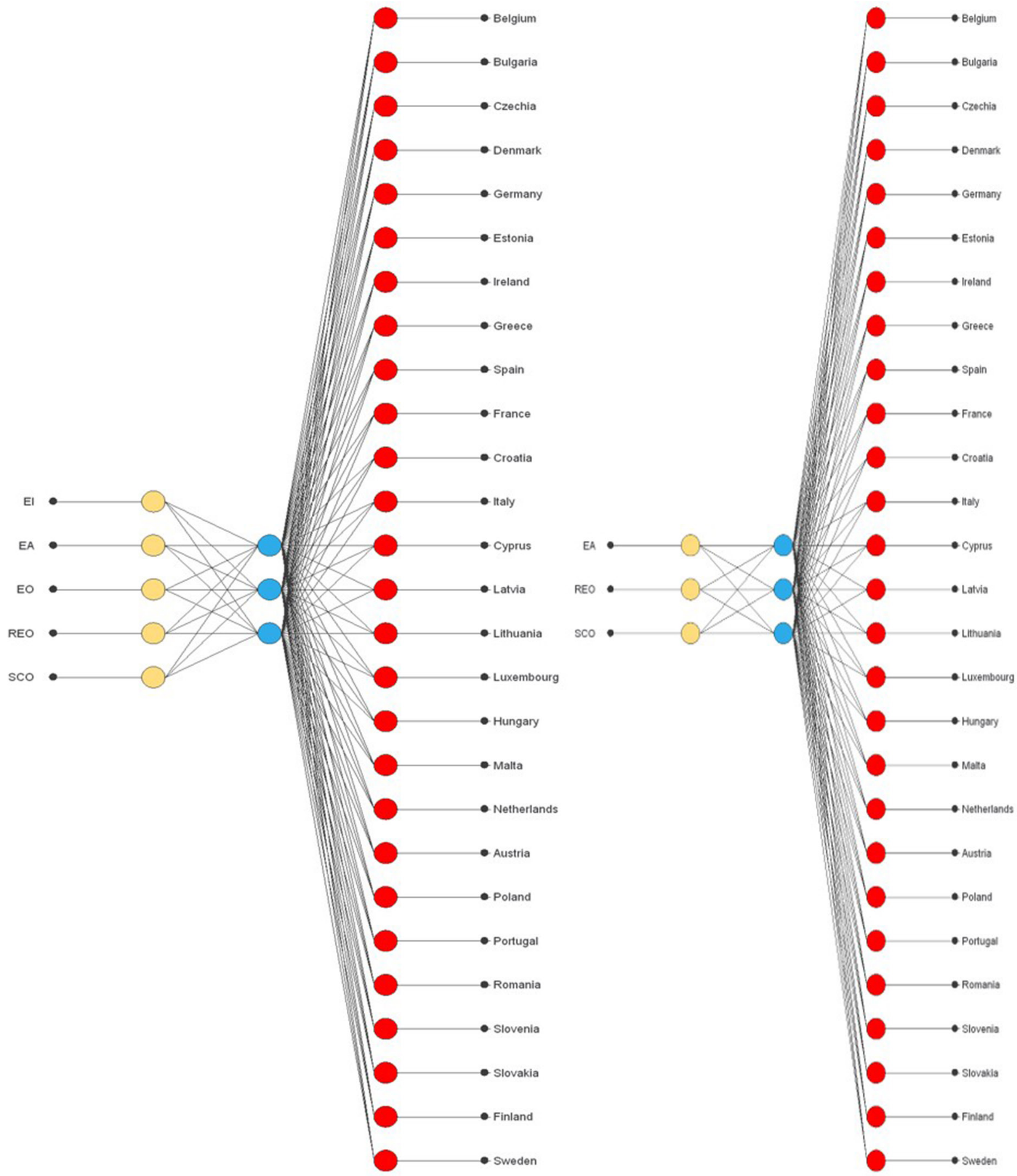

Figure 3. Neural network architecture for the eco-innovation performances of the EU members 2018-2022

Source: Authors' calculation according to available data

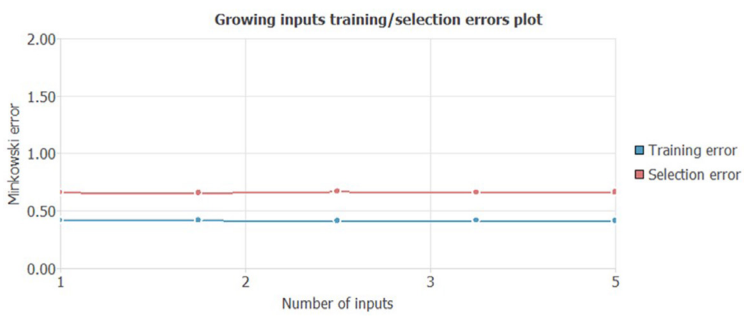

Figure 4. Quasi-Newton method and training sessions

Source: Authors' calculation according to available data

6. FUTURE RESEARCH DIRECTIONS

Possible future research could refer to the application of methods for multi-criteria decision-making in the ranking of European Union countries according to eco-innovation performances. Furthermore, different methods should be used to determine the value of the weighting coefficients of the sub-indicators, whereby neural network algorithms can have a significant contribution.

7. CONCLUSION

According to presented research and analysed data, Slovenia, Czechia, Estonia and Sweden have achieved significant improvement in eco-innovation activities, especially from 2018 to the 2022 year. Estonia's performance on CE indicators shows relative strength in business operations and relative weakness in societal behaviors. SMEs play a crucial role in the Estonian economy and contribute to 76 % of the added value generated by all Estonian companies (this is 18% above the respective EU average). They have advantages in terms of flexibility that put them into a central role in the implementation of the circular economy. On the other side Estonia, Italy, Luxembourg and Malta have shown great potential in resource efficiency outcomes and in socio-economic outcomes where Denmark, Austria and Finland have leadership roles. Luxembourg's relative strengths are in resource efficiency outcomes, and its relative weaknesses are in eco-innovation activities. The driving policy is the national circular economy strategy, which has strong connections with other national strategies and policy documents. The challenges to transitioning towards a circular economy in Luxembourg include the scarcity of circular business models, the complexity of value chains with large segments outside of Luxembourg, and the lack of awareness from the general public and the business community. Italy's National Strategy for a Circular Economy sets a comprehensive plan for improving its performance in waste management, supporting the reuse and repair of products, and strengthening the existing regulatory instruments targeting specific sectors and initiatives. Policymakers can use the results of neural network analysis to identify promising areas for research and development and eco-innovation investment, evaluate the effectiveness of eco-innovation policies over time, and analyze public awareness around environmental issues and eco-innovations.

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