DOI 10.17234/SocEkol.34.2.3
UDK 330.35(497.5) 338.2:502(497.5)

Izvorni znanstveni rad
Primljeno: 26.03.2025.
Prihvaćeno: 01.07.2025.

A NEW APPROACH TO ENHANCING SUSTAINABLE ECONOMIC GROWTH IN CROATIA: AN ANFIS ANALYSIS OF VARIABLE INTERPLAY

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Abstract
Economic growth rests on human capital, along with natural resources, technological innovation and capital, which points to a strong interdependence between the quality of effective management and production inputs. Energy efficiency is an effective instrument for achieving competitiveness and economic growth. While renewable energy in the energy mix can reduce import dependence and energy supply uncertainty, as well as help decarbonize industry, exploiting synergies between energy and industrial policies will be key for achieving competitiveness. This scientific paper explores modalities for improving the management of energy efficiency measures through an analysis of the interdependence of selected variables and their impact on the observed output variables, energy efficiency and energy productivity. A new approach indicates the variables that should be considered when choosing the direction for Croatia's faster transition and economic prosperity. The selected variables tend to be nonlinear, so fuzzy logic is used to reduce uncertainty in decision-making in the presence of such nonlinearities. The adaptive neuro-fuzzy inference system (ANFIS) was deployed for the new approach in connecting such variables and yielding better modelling results. Additionally, expert knowledge was introduced through a survey of Croatian entrepreneurs, for validation purposes. The analysis of the interdependence of variables provides valuable insight for future interventions, and in EU member states, indicates the need for a different model of effective governance. In this context, an improved, optimal model is constructed, which can, if applied, help Croatia achieve faster economic growth.

Keywords: *adaptive neuro-fuzzy inference system, Croatia, energy efficiency, innovative governance model, sustainable economic development*

1. INTRODUCTION

The European Union (EU) is investing significant resources to ensure the conditions for climate neutrality are created by 2050, as outlined in the EU Green Deal. The ambitious targets should, with the help of European structural financial instruments, lead to lower energy consumption, while also reducing greenhouse gas (GHG) emissions, thereby easing the increasing pressures on the climate. In this context, energy efficiency (EE) is increasingly recognized as an instrument for sustainable energy supply, reducing GHG emissions, improving security of supply and reducing import costs, but also promoting competitiveness and economic growth in the EU (Green Deal, 2019).

In addition, renewable energy sources (RES) have proven to be key to balancing the energy mix, which will help reduce EU countries' dependence on imports, make energy affordable for their residents, create new green jobs, and enable faster recovery of climate-degraded areas. This could eventually lead to the slowing down of climate change and ultimately to the achievement of climate neutrality. For this purpose, the EU secured significant funds from various budget lines.

The transition to a climate-neutral economy requires, along with increased investment efforts, a significant involvement of entrepreneurs and citizens in the implementation of public policies to achieve the established goals. Arguments that the effects of energy efficiency go beyond energy savings, and that their impact should be viewed through social, environmental, and economic context, provide tools for industry and decision-makers to find these connections and achieve multiple benefits (Fawcett, Killip, 2019). Sustainable development is a key strategic determinant of cohesion policy, so in that context, an effective management model for addressing the challenge of achieving the necessary level of economic development in less-developed EU member states is extremely important in such an accelerated and ambitious plan.

Croatia is among the smallest polluters within the EU, so it is necessary to link the management of EE and RES with the achievement of greater competitiveness and economic growth. The interaction of security of supply, import dependence and the price component of energy products plays a vital role and is of great importance for economic growth. In addition, the energy transition is an opportunity to find and apply innovative management models and to formulate better management policies to the benefit of citizens in terms of better air quality, healthier environment and improved health in general (Markuz, 2022).

The basis for further analysis rests on the clustering of variables through self-organising networks previously determined in the initial research by Markuz (2022). Clustering showed that variables often behave nonlinearly, so it was necessary to resort to modelling with fuzzy logic, which significantly expands the characteristics of standard approaches. Adaptive neuro-fuzzy systems (ANFIS) fit well here, and the MATLAB program package serves as a computational support since new approaches and innovative models aim to provide tools for management structures and public services in adopting more effective policies and prioritizing measures with the aim of faster transition and sustainable development and growth of the Croatian economy.

The hypotheses of this research are:

1. The selected variables provide better insight into the interdependencies of key energy efficiency factors. The application of fuzzy logic in the created ANFIS models, however, improves classical approaches by reducing uncertainty, thus enabling more precise decision-making in circumstances of complex nonlinear relationships.
2. The innovative management model supported by European Structural and Investment Funds (ESI funds) provides an opportunity for a faster and more efficient transition of Croatia to a sustainable economy.

The significance of this research lies in a new way of connecting parameters for the achievement of policy goals, as well as modelling that captures the very essence of cohesion policy in an innovative way. The research highlights the way in which individual states should set priorities for investment, as well as the importance of simultaneous implementation of individual policies, while previous research has mostly gone in the direction of observing individual policies, that is, each goal separately. Selected countries, as well as variables for further analysis, will be described, and their selection will be elaborated in the data and methodology part of the research.

The rest of the paper follows the following structure: Section 2 provides an overview of the relevant literature in this area; Section 3 describes the data and methodology; Section 4 presents the results; and Section 5 provides conclusions and implications.

2. THEORETICAL FRAMEWORK / LITERATURE REVIEW

Faced with the global energy challenges of the 21st century, the EU is leading the transition towards clean energy, striving for a more secure, competitive and sustainable energy system that will respond to the existential challenge of our time (Iarmenco et al., 2020). EE has been recognized as a cost-effective way to increase energy security, improve economic competitiveness and promote sustainability (Ang and Goh, 2018).

The very high and volatile global energy prices over the last decade have put pressure on finances, especially for countries that are forced to import a higher percentage of their energy. Energy sector is undoubtedly an integral part of each economy; therefore, EE should be seen as an opportunity for economic development (Markuz, 2022; Brlečić Valčić and Markuz, 2024). In this regard, an effective policy program on EE and demand management should consider public finances, institutions, hierarchy, domestic prices, sectors, and EU support (Hafner and Tagliapietra, 2016).

Moreover, IRENA (2024) in its reports highlights that the world needs to keep up the pace if we want to catch up with the 2030 goals on RES. However, growing at 10% will no longer be enough; it should be about 16% from 2022 to 2030. Economic analyses emphasizes that the benefits of increasing RES outweigh cost competitiveness, and estimates of the increase in global GDP in this regard are between 0.6 and 1.1% (IRENA, 2016). In addition to the aforementioned predictions, there are increases in direct and indirect employment associated with this scenario. On the other hand, inconsistent implementation of the envisaged measures for EE and RES over time will increasingly highlight the difficulties that individual countries will face in effectively planning future energy demand in the context of supply and affordability (Goh and Ang, 2020).

This is particularly important in the context of the long-term strategic guidelines of the EU related to the role of total factor productivity in stimulating future growth and competitiveness (Jakšić et al., 2020).

Croatia entered the transition process with a low level of productivity and competitiveness (Corbo et al., 1992; Ofer, 1992), and reaching the level of developed countries of the EU requires structural reforms (Kegels and van der Linden, 2011), greater investment in research and development (Lopez-Rodriguez and Martinez-Lopez, 2017) and technological innovation (Masso and Vahter, 2008). Therefore, measures and policies for EE and the use of RES must be indirectly linked to these issues in the context of sustainable economic development (Brlečić Valčić and Markuz, 2024). Therefore, to achieve the set goals of the EU, it is necessary to consider the importance of management, the quality of institutions and the socioeconomic factors that drive environmental sustainability goals for preservation from degradation (Saba et al., 2025). This could, after all, lead to the slowing down of climate change and ultimately the achievement of climate neutrality.

This problem requires a more modern approach in terms of clustering to develop a model for prioritizing strategic actions. New approaches must consider nonlinearities, connect quantitative and qualitative parameters, incorporate expert knowledge in decision-making systems, and account for the uncertainty in decision-making (Brlečić Valčić and Bagarić, 2017). Fuzzy logic in this context significantly expands the characteristics of classical approaches and represents one of the possible solutions to these problems (Gil-Lafuente et al., 2012).

3. DATA AND METHODOLOGY

To analyze and evaluate existing EE and RES measures for sustainable economic development, it is important to use open access, publicly available and verifiable data. Relevant data, especially the factual connection between the invested funds and the indicators of the impact on these investments, is obtained mainly from the European portals Eurostat and Cohesion Data. For the purposes of initial research, according to Markuz (2022), 18 countries were selected. Common elements for further analysis and modelling were that 1) these countries had fewer than 11 million inhabitants and 2) EU funds were available to them for the period 2015-2019. This was important due to the fact that true effects of consumption can only be observed at the end of the Multiannual Financial Framework (MFF). Moreover, 2019 was a non-standard year, in the context of disruption in entrepreneurial ventures globally and in the EU (caused by the pandemic and energy crisis), so taking such data into account could call into question a coherent interpretation of the results, especially those relatively stable and relevant effects within the time frame. The selection itself was also influenced by data comparability issues caused by changes in certain methodologies for calculating EE and RES (Markuz, 2022). Selected countries were Austria, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Latvia, Lithuania, Luxembourg, Malta, Portugal, Slovakia, Slovenia and Sweden. However, preliminary analyses and clustering of 32 variables conducted by Markuz (2022) proved that only 18 variables showed a connection with Energy Efficiency and Energy Productivity, so these were used for further analyses and modelling. Interconnected variables were: Input 1 Energy Efficiency; Input 2 Energy productivity; Input 3 Dependence on energy imports; Input 4 Population unable to heat their homes sufficiently due to poverty status; Input 5 Share of renewable energy in gross final energy consumption; Input 6 Electricity generation capacities by main fuel groups and operator; Input 7 GERD by performance sector; Input 8 R&D personnel by performance sector; Input 9 Share of state budget appropriations or R&D expenditure; Input 10 Employment in high and medium-high technology; Input 11 Individuals: internet use; Input 12 E-government activities; Input 13 Promotion of e-commerce for enterprises; Input 14 GDP at market prices; Input 15 GDP per capita; Input 16 Gross value added at basic prices; Input 17 ESIF spent (2014-2020); Input 18 Education and training participation (Markuz, 2022).

ANFIS was deployed for the analysis of the correlation and causality of the observed parameters. ANFIS itself is based on the fuzzy logic inference system (FIS). This method of inference, in a narrow sense, can be described as a logical system, "an extension of binary logic, while in a broader sense it is almost synonymous with fuzzy set theory" (Brlečić Valčić, 2014:107). As an ambiguous logic, where the truth value of variables can be any real number between 0 and 1, it is used with the concept of partial truth, where the truth value can vary between completely true and completely false (Markuz, 2022).

Lotfi Zadeh, mathematician, creator of the fuzzy set theory, introduced the term fuzzy logic in 1965. Its basic meaning can be conveyed through the fact that when describing real-world problems and finding effective solutions to them, it is necessary to manage fuzzy situations such as uncertainty, indeterminacy, and incompleteness. By incorporating fuzzy set theory into the traditional analytical hierarchy process, this approach has become a suitable tool for solving multi-criteria decision-making problems in the real world (Gil-Lafuente, 2005; Kiang and Fisher, 2008).

For the purposes of the research, Markuz (2022) relies on the FIS and ANFIS methodology, complemented by Brlečić Valčić's approach, where it is worth highlighting five basic steps that make up each FIS such as selection of input and output variables and definition of their names and value ranges; description of input and output variables with linguistic values; selection (type, number) and modelling of the membership function for each input and output variable; determination of the necessary fuzzy IF-THEN rules that connect input and output variables with linguistic values, application of fuzzy operators and implication methods and sharpening (defuzzification) (Brlečić Valčić, 2014).

However, ANFIS, as a fuzzy inference system, has a different architecture and learning procedure implemented within adaptive networks than the classical FIS. By using a hybrid learning procedure, ANFIS can construct its own input-output mapping in the form of fuzzy IF-THEN rules and prescribed input-output data pairs (Jang, 1993; Valčić et al., 2011). The ANFIS architecture is also used "to model nonlinear functions, identify nonlinear components on-line in a control system, and predict a chaotic time series, all yielding remarkable results" (Jang, 1993:665).

To illustrate the ANFIS architecture, the assumption was used that for some two input parameters x and y and one output parameter f, with two fuzzy rules, in that case the same can be expressed as (Jang, 1993; Valčić et al., 2011): Rule 1: IF x is A1 and y is

B1 THEN; Rule 2: IF x is A2 and y is B2 THEN, where x and y are inputs, Ai and Bi are fuzzy sets, fi is a linear function of the input, pi, qi and ri are parameters that are adjusted during the training phase, as shown in Figure 1 below (Valčić et al., 2011).

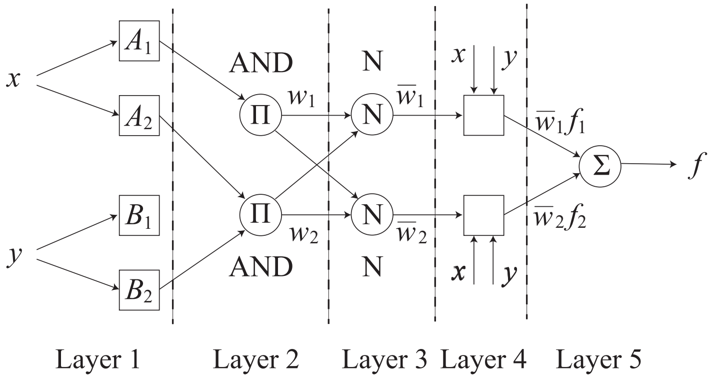

Figure 1. *ANFIS architecture*
Source: Valčić et al. (2011) according to Markuz (2022)

Finally, the ANFIS output is "calculated by means of consequent parameters. The residuals between the calculated ANFIS output values and the real outputs are used to adjust the assumed parameters for the next epoch based on the standard learning algorithm with error backpropagation" (Valčić et al., 2011:377).
The goal of training (learning) is to minimise the differences between the actual and assumed parameters by adjusting the assumed and consequent parameters (Valčić et al., 2011). "The learning algorithm adjusts the parameters {*ai*,*bi*,*ci*} and {*pi*,*qi*,*ri*} in order to determine the optimum between the ANFIS output and the training output. When the assumed parameters {*ai*,*bi*,*ci*} are determined, the ANFIS output model can be written

as: $$f = \frac{w_1}{w_1 + w_2} f_1 + \frac{w_2}{w_1 + w_2} f_2, \quad (1)$$

or $$f = (\overline{w}_1 x) p_1 + (\overline{w}_1 y) q_1 + (\overline{w}_1) r_1 + (\overline{w}_2 x) p_2 + (\overline{w}_2 y) q_2 + (\overline{w}_2) r_2, \quad (2)$$

which represents a linear combination of adjustable consequent parameters p1, q1, r1, p2, q2 and r2" (Valčić et al., 2011:377). After this phase, the least squares method is used to determine the optimal values of these parameters. To avoid the problems related to the excessively large area of determining the results, when the assumed parameters are not fixed, a hybrid learning algorithm is used that combines the least squares method with the backpropagation learning algorithm (Valčić et al., 2011). After the optimal values of the consequent parameters are determined by the least squares method, the adjustment of the assumed parameters is carried out by the gradient descent method (Valčić et al., 2011). Finally, the ANFIS output is calculated using the consequent parameters. The variance between the calculated ANFIS outputs and the actual outputs is used to adjust the assumed parameters for the next epoch based on the standard backpropagation learning algorithm (Valčić et al., 2011).

Data analysis within the ANFIS architecture consists of several main steps, which include loading and distributing training and testing data, FIS generation, FIS training, and ANFIS testing and validation (Valčić et al., 2011). The detailed procedure is shown in Figure 2.

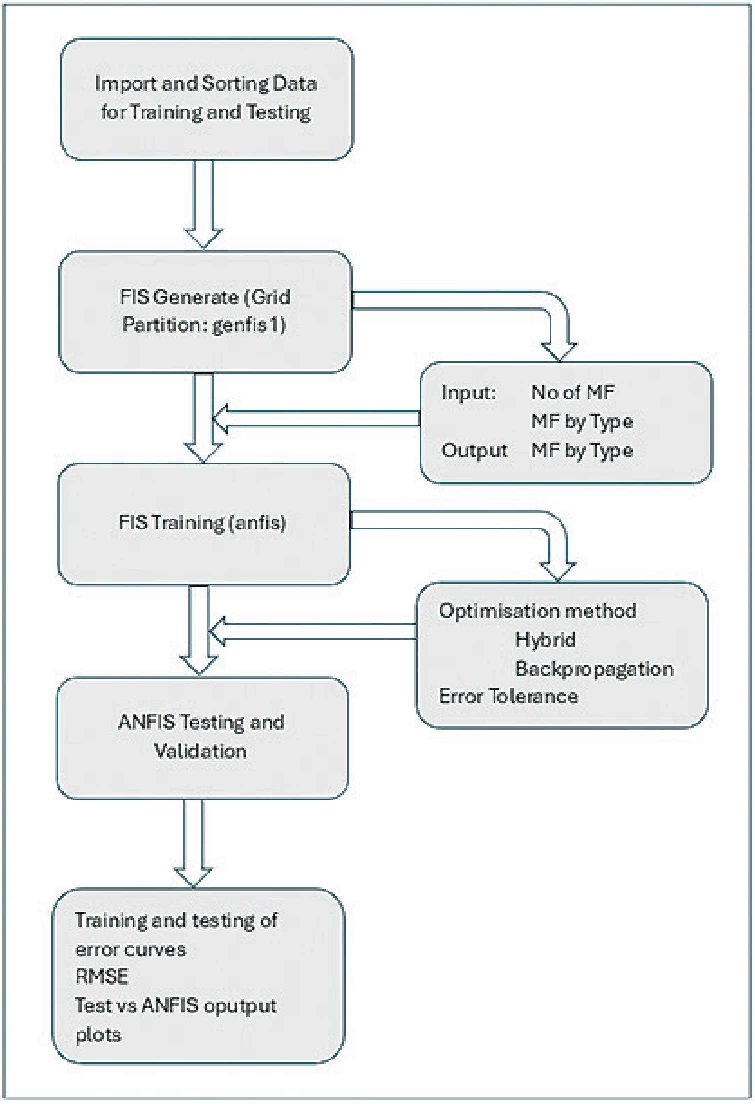

Figure 2. *ANFIS creation and validation process*
Source: Systematization of the author based on Valčić et al. (2011)

Finally, it should be noted that the success of the ANFIS model is mainly assessed by statistical indicators used in the implementation of the artificial neural network. Therefore, for this purpose, according to Markuz (2022), the root mean square error, RMSE, is defined as:

$$RMSE = \sqrt{MSE} = \sqrt{\frac{1}{N}\sum\nolimits_{n=1}^{N}(R_n - O_n)^2}. \tag{3}$$

Due to the structure of the data, they were previously standardised for the purpose of creating an ANFIS model for further analysis. Standardization replaces values with their Z scores to ensure consistency, i.e., so that the data have the same content and format, and the data tracking is easy to compare and redistributes the features with their mean values (Markuz, 2022), so that:

mu = 0 and standard deviation sigma = 1 (4)

x_standardised = (x - mean(x)) / std(x) (5)

The relevance of ANFIS as a methodology (or research tool) is indicated by the fact that 8631 studies using ANFIS were published in the relevant Web of Science Core Collection database, of which 633 papers were in environmental research, 37 in the field of economics and 28 in the field of business (Markuz, 2022).

The MATLAB software package was used to create and model the ANFIS models. The separate characteristics of each individual model are:

The characteristics of the ANFIS 1 model are: number of nodes: 193; number of linear parameters: 405; number of non-linear parameters: 36; total number of parameters: 441; number of training data pairs: 95; number of data pairs to check: 0; number of fuzzy rules: 81; minimum training RMSE = 0.0222417 (Markuz, 2022). Figure 3 shows the success of training the network for the ANFIS 1 model as follows:

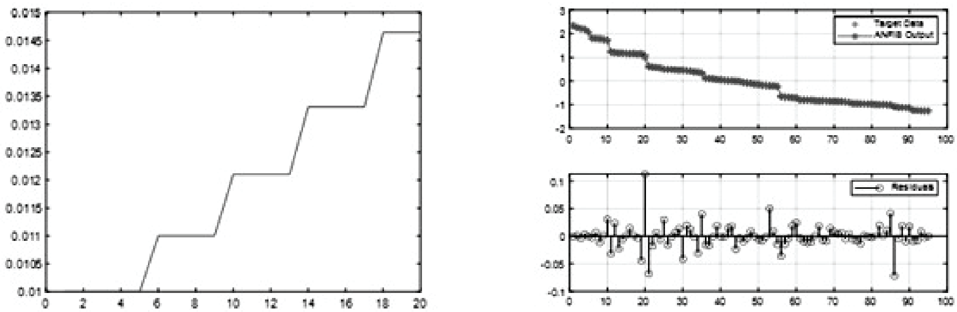

Figure 3. *Training characteristics of the ANFIS 1 model*
Source: Systematization of the author in MATLAB according to Markuz (2022)

The characteristics of the ANFIS 2 model are: number of nodes: 78; number of linear parameters: 108; number of non-linear parameters: 27; total number of parameters:

135; number of training data pairs: 95; number of data pairs to check: 0; number of vague rules: 27; minimum training RMSE = 0.0687093 (Markuz, 2022). Figure 4 shows the success of network training for the ANFIS 2 model as follows:

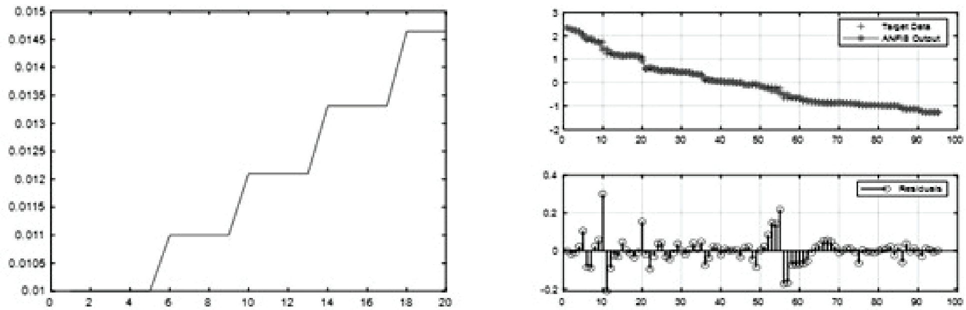

Figure 4. *Training characteristics of the ANFIS 2 model*
Source: Systematization of the author in MATLAB according to Markuz (2022)

The characteristics of the ANFIS 3 model are: number of nodes: 193; number of linear parameters: 405; number of non-linear parameters: 36; total number of parameters: 441; number of training data pairs: 95; number of data pairs to check: 0; number of fuzzy rules: 81; minimum training RMSE = 0.0284573 (Markuz, 2022). Figure 5 shows the success of network training for the ANFIS 3 model as follows:

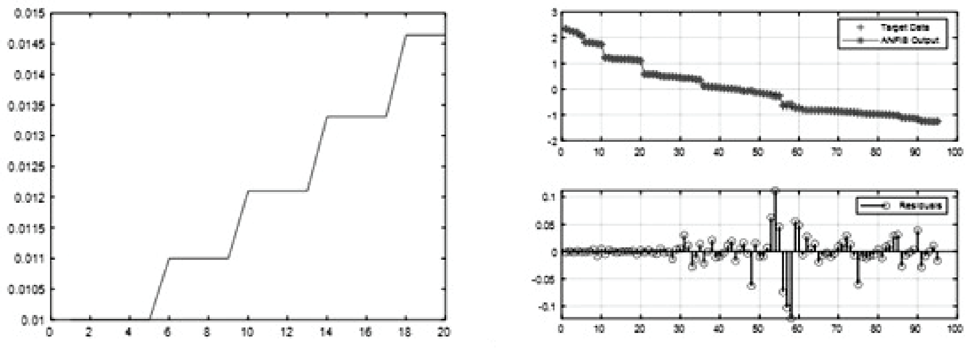

Figure 5. *Training characteristics of the ANFIS 3 model*
Source: Systematization of the author in MATLAB according to Markuz (2022)

The characteristics of the ANFIS 4 model are: number of nodes: 78; number of linear parameters: 108; number of non-linear parameters: 27; total number of parameters: 135; number of training data pairs: 95; number of data pairs to check: 0; number of vague rules: 27; minimum training RMSE = 0.0294762 (Markuz, 2022). Figure 6 shows the success of network training for the ANFIS 4 model as follows:

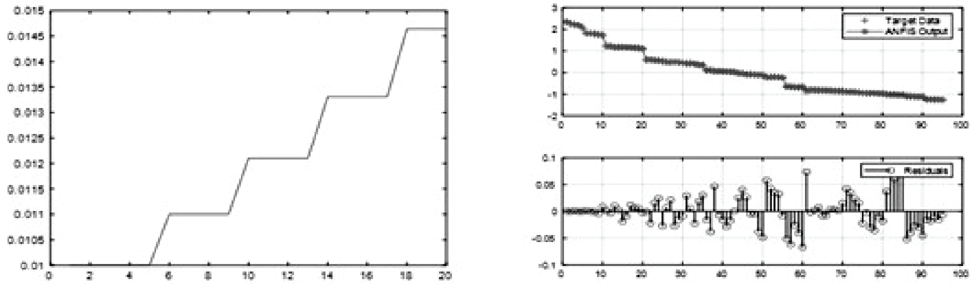

Figure 6. *Training characteristics of the ANFIS 4 model*
Source: Systematization of the author in MATLAB according to Markuz (2022)

The characteristics of the ANFIS 5 model are: number of nodes: 78; number of linear parameters: 108; number of non-linear parameters: 27; total number of parameters: 135; number of training data pairs: 95; number of data pairs to check: 0; number of vague rules: 27; minimum training RMSE = 0.138285 (Markuz, 2022). Figure 7 shows the success of network training for the ANFIS 5 model as follows:

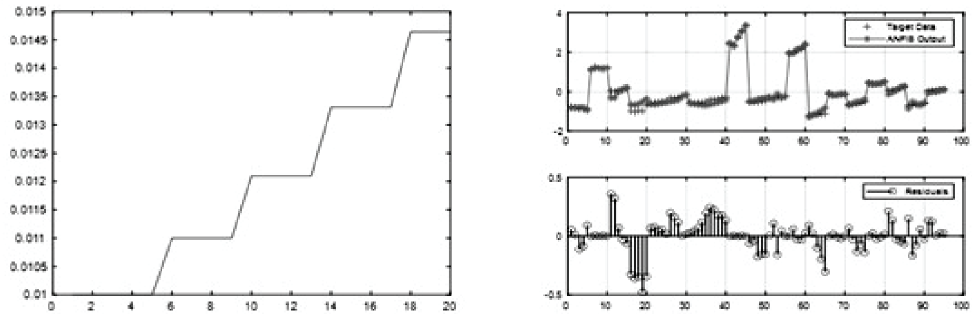

Figure 7. *Training characteristics of the ANFIS 5 model*
Source: Systematization of the author in MATLAB according to Markuz (2022)

In all the displayed images of the characteristics of the ANFIS model, it can be seen that each individual network is correctly trained (the left part of each individual image), because the correct training is indicated by the correct stepwise elevation of the blue line. From the right part of each individual image, it is visible that the network for each model covered the target data, because the dark blue lines are almost completely covered by the red ones, regardless of the number and structure of the residuals. The low values of the RMSE indicators point to the quality of the presented models. The models created in the analytical part are presented using 3D and 2D topography to facilitate the conclusion and interpretation of the obtained results.
Moreover, previous research stipulates that policymakers, when creating programs on energy efficiency, should take into account public finances, institutions, hierarchy, domestic prices, sectors and EU support (Hafner, Tagliapietra, 2016), so to further sup-

port the arguments and validate the results, a survey, described in more detail in Section 4, was conducted among 138 Croatian entrepreneurs, a key factor for achieving EE in using EU funds and facilitating a faster transition towards a higher level of productivity and competitiveness.

4. RESULTS AND DISCUSSION

Considering the research conducted by other authors and the conclusions of the SOM analysis and the analysis using p-values by Markuz (2022), this analysis was conducted using the ANFIS model for each individual set of parameters related to Energy Efficiency and Energy Productivity, and in the context of economic development, based on the established EU strategies.

For this purpose, the analysis starts with Model 1 (ANFIS 1).

The intention of further analysis with this model is to clarify (in terms of the necessary investments) the interconnection between RES, R&D and digital inclusion. Therefore, the following input data were selected: Input 1 – Share of renewable energy in gross final energy consumption; Input 2 – R&D personnel, by performance sector; Input 3 – E-government activities of individuals via websites; Input 4 – Digital Single Market – promoting e-commerce for businesses. The output parameter is EE (Markuz, 2022). Figure 8 and Figure 9 show Model 1 in 3D and 2D formats.

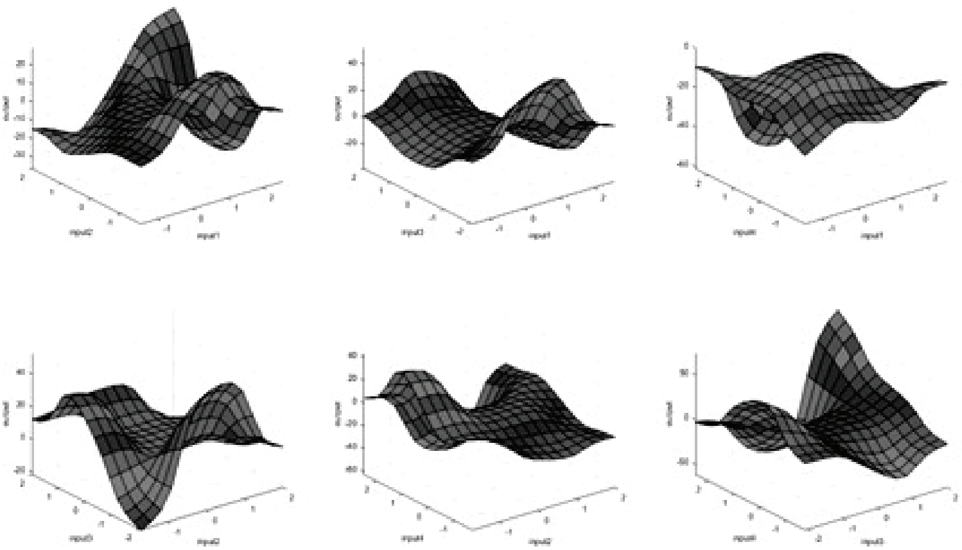

Figure 8. *Model 1 in 3D format*
Source: Systematization of the author in MATLAB according to Markuz (2022)

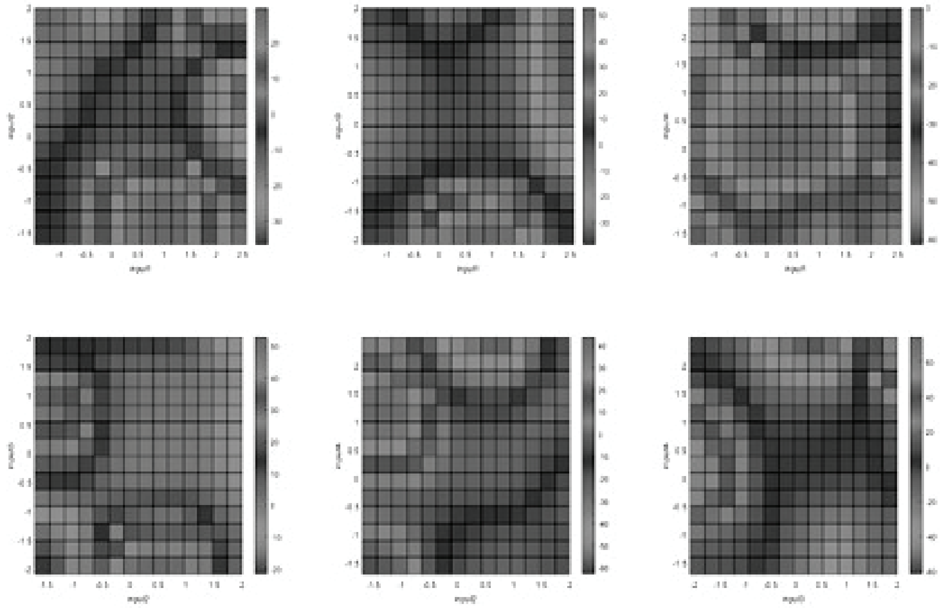

Figure 9. *Model 1 in 2D format*
Source: Systematization of the author in MATLAB according to Markuz (2022)

According to the analysed data in the selected time period , it can be observed that higher values of the EE parameter appear with medium and high values of the Share of renewable energy in gross final energy consumption parameter, lower and medium values of the R&D personnel parameter, by performance sectors, very low values of the E-government activities of individuals via websites parameter and medium and high values of the Digital Single Market – promotion of e-commerce for businesses parameter. However, low values of the EE parameter, as the analysis conducted in Model 1 shows, can appear with very high values of the Share of renewable energy in gross final energy consumption parameter with the simultaneous occurrence of medium values of the R&D personnel parameter by performance sectors and medium and high values of the E-government activities of individuals via websites parameter and extremely high values of the Digital Single Market – promotion of e-commerce for businesses parameter.

Therefore, it should be concluded that EE in the context of economic productivity and growth and in accordance with the EU guidelines and strategies, primarily requires a higher share of renewable energy in gross final consumption.

The development of the Digital Single Market, which is also one of the prerequisites for productivity, is directly dependent on the previously mentioned condition (high level of EE and high share of renewable energy in gross final consumption) and should drive the need for a larger share of R&D personnel, which in turn should also stimulate e-government activities of individuals. The observed countries show a need for investment and further development in the aforementioned areas, and in the context of economic growth and development (Croatia is included in the scope of these countries).

Further clarification of the conclusions obtained from the analysis based on Model 1, and in terms of the currently extremely important variable of energy import dependence, is made based on the analysis of Model 2 (ANFIS 2) and the following parameters were selected for it: Input 1 – Dependence on energy imports; Input 2 – Share of approved state budget funds or expenditures for R&D; Input 3 – Individuals – Internet use. Output – EE (Markuz, 2022). Figure 10 shows Model 2 in 3D and 2D formats.

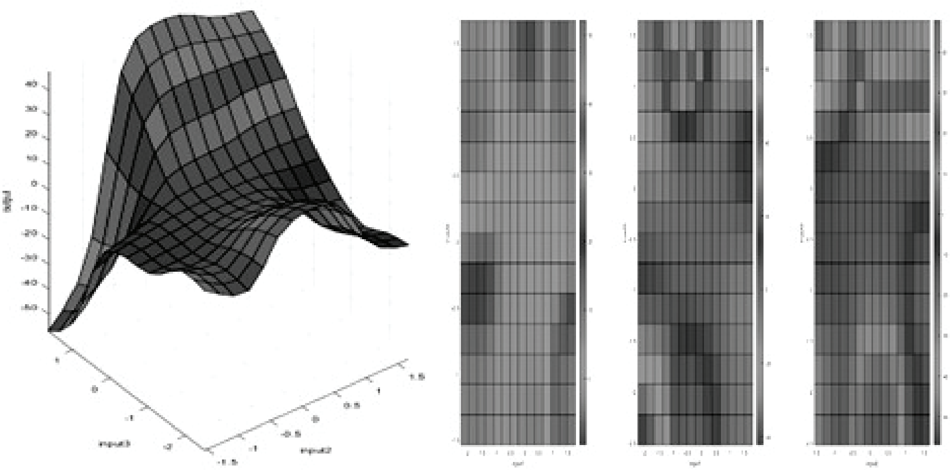

Figure 10. *Model 2 in 3D and 2D format*
Source: Systematization of the author in MATLAB according to Markuz (2022)

According to the analysed data, high values of EE occur in the combination of very high values of the parameter Dependence on energy imports with simultaneously low values of the parameter Share of approved state budget funds or R&D expenditures, low to medium values of the parameter Dependence on energy imports in combination with very high values of the parameter Individuals – Internet use and medium to high values of the parameter Share of approved state budget funds or R&D expenditures with simultaneously very high values of the parameter Individuals – Internet use.

It should therefore be concluded that highly efficient countries, which invest in R&D and turn to a digital way of doing business and living, also support EE, or are associated with higher EE. The analysis results also indicate the existence of a still significant share of countries with industries that create a high dependence on energy imports and the need for a higher share of R&D expenditures that would contribute precisely to digitalisation and the creation of more efficient production (or service activities).

In the case of a combination of a very low share of the parameter Dependence on energy imports with a simultaneous very low share of the parameter Individuals – Internet use according to the analysis (display of the relationship between Input 1 and Input 3), high negative values for EE may occur. According to the same presentation, such a possibility also occurs with a combination of very high values of the parameter Dependence on energy imports with at the same time very high values of the parameter Individuals – Internet use. Therefore, in the context of creating industrial policies and development priorities of individual industrial branches, it is necessary to consider energy availability and dependence in time.

According to the analysis carried out, high negative values for EE can also occur in the case of very low values of the parameter Share of approved state budget funds or expenditures for R&D with at the same time very high values of Individuals – Internet use (display of the relationship between Input 2 and Input 3). The policies of individual states, therefore, should be able to direct the population's abilities related to digitisation in a timely manner, while ensuring sufficient state budget funds, and focus R&D on identifying the potential of individuals and creating industrial policies based on this for the purpose of EE.

The social dimension of the observed problem in this research was analysed by Model 3 (ANFIS 3) based on the following data: Input 1 – The population that, due to their poverty status, cannot heat their homes sufficiently; Input 2 – Employment in high and medium-high technology; Input 3 – Gross added value in basic prices; Input 4 – Participation rate in education and training. Output – EE (Markuz, 2022). Figure 11 and Figure 12 show Model 3 in 3D and 2D formats.

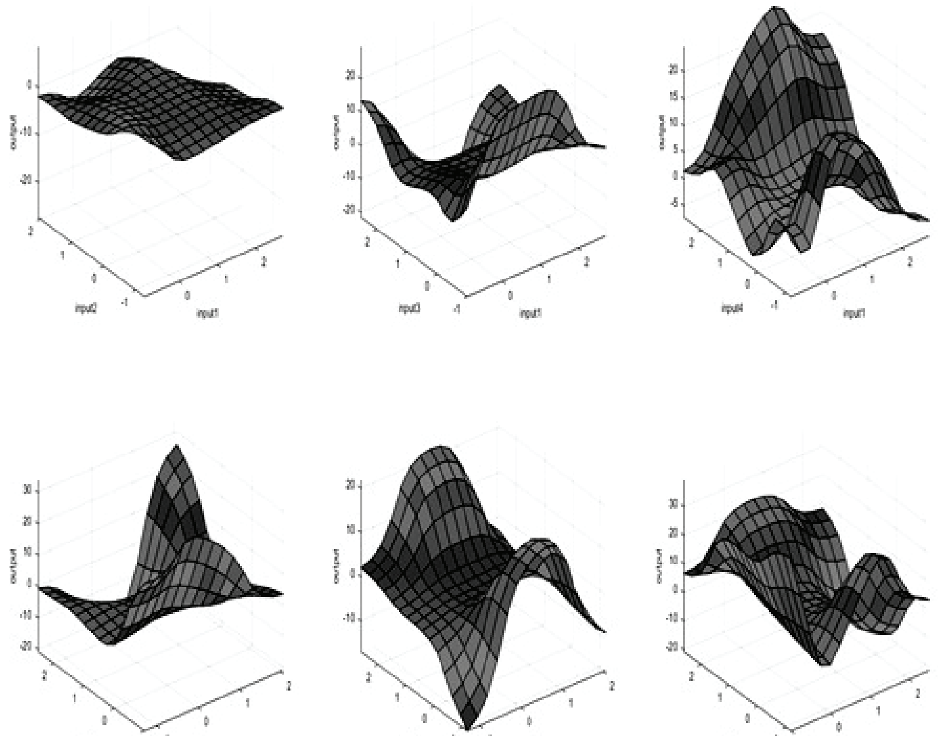

Figure 11. *Model 3 in 3D format*

Source: Systematization of the author in MATLAB according to Markuz (2022)

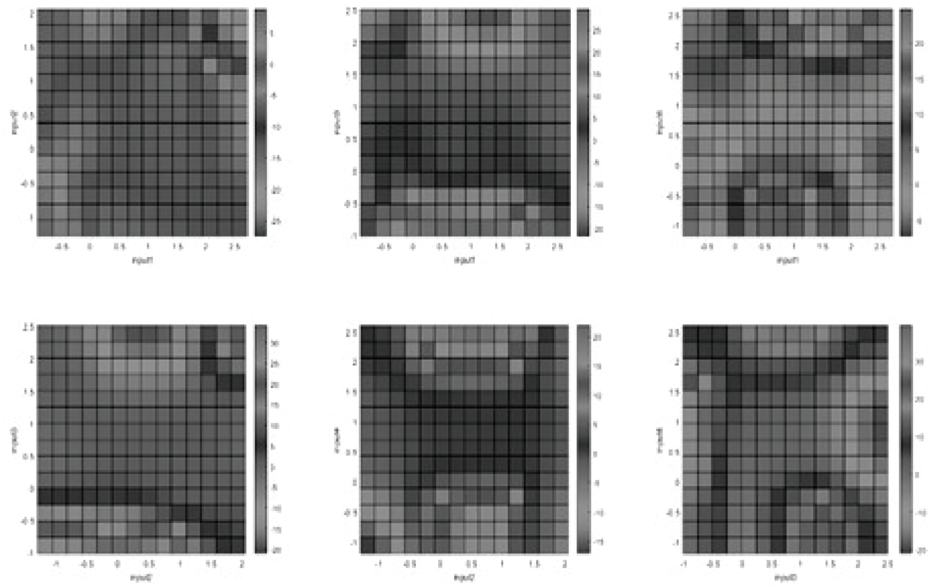

Figure 12. *Model 3 in 2D format*
Source: Systematization of the author in MATLAB according to Markuz (2022)

According to the analysis conducted, in Model 3 it is evident that very low values of the parameter Population that due to poverty status cannot sufficiently heat their homes, together with very low values of the parameter Employment in high and medium-high technology, have an impact on a high level of EE. This also indicates the fact that larger amounts of financial resources remain available directly for EE, and encourage entrepreneurs to employ highly educated, technologically qualified experts, and reduce the need for social benefits. Although these indicators clearly indicate high EE, given the observed parameters, in the coming period, economic development should still be guided by the implementation of strategic guidelines for increasing investments in technological development and high technologies.

Medium to high values of the parameter Population that cannot sufficiently heat their homes due to poverty status, along with very low values of the parameter Gross value added in basic prices that indicate high EE, also reflect savings of individual members of society that are caused by poverty, not choise, in the case of low gross value added, because the governments of such countries (as well as the EU funds intended for this) are not doing enough to prevent and completely avoid such scenarios.

Regarding the parameter Employment in high and medium-high technology, and according to the analysis conducted with Model 3, high EE is indicated by the mean values of the same parameter, along with very low values of the parameter Gross value added at basic prices (display of the relationship between Input 2 and Input 3). This also indicates the direction of industrial policies that should contribute to a higher rate of gross value added. At the same time, the mean values of Employment in high and medium-high technology, along with very high values of the parameter Participation rate in education and training, which indicate high EE, confirm the abovementioned conclusion (display of the relationship between Input 2 and Input 4).

The last view in Model 3 (ratio of Input 3 and Input 4) of the relationship between the parameters Gross value added at basic prices and the Participation rate in education and training, which contribute to high EE only with low, or more precisely negative, values, also builds on the aforementioned, meaning that industrial policy is still not moving in the desired direction of achieving EE.

Negative values in EE, according to this analysis, may appear in the relationship between very high values of the parameter Population that due to poverty status cannot sufficiently heat their homes with very high values of the parameter Employment in high and medium-high technology; then a combination of medium values of the parameter Population that due to poverty status cannot sufficiently heat their homes with very high values of the parameter Gross value added at basic prices; very low and very high values of the parameter Population that due to poverty status cannot sufficiently heat their homes with very high values of the parameter Participation rate in education and training; medium values of the parameter Employment in high and medium-high technology with very high values of the parameter Gross value added at basic prices; very low values of the parameters Employment in high and medium-high technology and Participation rate in education and training and very high values of the parameter Gross value added at basic prices with very high values of the parameter Participation rate in education and training. In summary, in relation to the presented problem observed through the parameters in Model 3, Gross value added at basic prices and Participation rate in education and training are directly related parameters, and EE

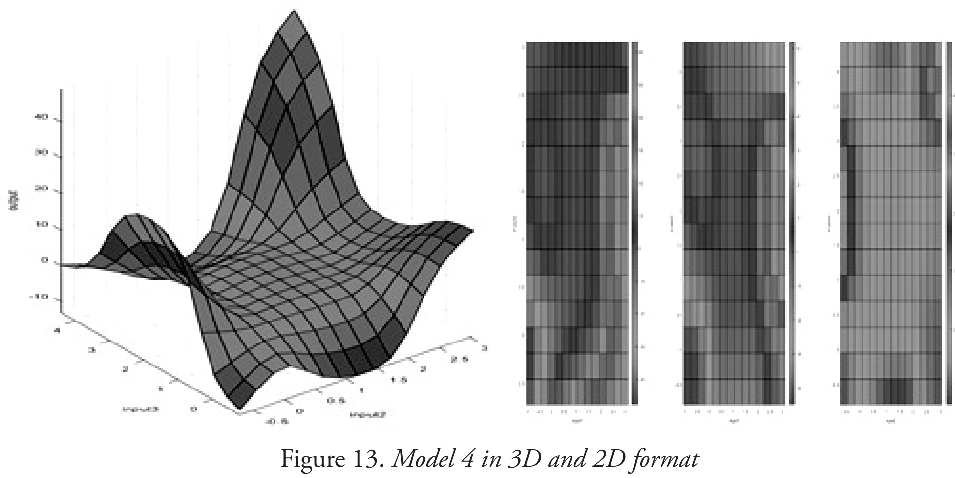

Figure 13. *Model 4 in 3D and 2D format*
Source: Systematization of the author in MATLAB according to Markuz (2022)

depends on them the most. The parameter Population that due to poverty status cannot sufficiently heat their homes depends on EE, and the parameter Employment in high and medium-high technology depends on the parameter Population that due to poverty status cannot sufficiently heat their homes due to social policy support that will have to be greater than those that would be necessary to invest in entrepreneurs to employ and train experts in high technology.

Finally, the significance of ESIF in the observed topic of EE for the purpose of economic development is analysed by Model 4 (ANFIS 4) based on the following data: Input 1 – Electricity generation capacities by main fuel groups and operator; Input 2 – GERD by performance sector; Input 3 – ESIF (2014-2020). Output – EE (Markuz, 2022). Figure 13 shows Model 4 in 3D and 2D formats.

According to the analysis by Model 4, it is evident that very high values of the parameter Electricity production capacities by main fuel groups and operator, in combination with medium and high values of the GERD by performance sector parameter, contribute to very high values of EE. Likewise, the analysis with this combination of selected parameters indicates high values of EE and very high values of the parameter Electricity production capacities by main fuel groups and operator, while at the same time the parameter ESIF spent (2014-2020) is at mean values.

Looking at the third part of the presentation of the analysis made by Model 4 (the ratio of Input 2 and Input 3), it can be concluded that very high values of the parameter ESIF spent (2014-2020), with at the same time very high values of the parameter GERD by performance sector, contribute to high values of EE.

On the other hand, based on this analysis, it can be concluded that low and negative values of EE can be caused by combinations of:

- very low values of the Electricity production capacity parameter by main fuel groups and operator, with simultaneously very low values of the GERD by performance sector parameter;
- very low values of the parameter Electricity production capacities by main fuel groups and operator, with simultaneously very low values of the parameter ESIF spent (2014-2020), but also very high values of the parameter Electricity production capacities by main fuel groups and operator, with simultaneously very high values of the parameter ESIF spent (2014-2020);
- low and medium values of the GERD by performance sector parameter, with at the same time very low values of the ESIF spent (2014-2020) parameter, but also medium values of the GERD by performance sector parameter, with at the same time very high values of the ESIF spent (2014-2020) parameter.

To conclude, it is clear from the analysis that high values of the parameter Electricity production capacities by main fuel groups and operator and the mean values of the parameter ESIF spent (2014-2020) are important for EE. The GERD by performance sector, from which very high values are expected in terms of EE, simultaneously requires very high values of the ESIF spent (2014-2020) parameter.

The data analysis in Model 5 (ANFIS 5) is related to energy productivity in the context of economic development. Following the previously conducted analysis using SOM and p-value by Markuz (2022), the parameters used in this analysis are: Input 1 – GERD by sector of performance; Input 2 – GDP at market prices; Input 3 – GDP per capita in PPS (purchasing power standard). Output – Energy productivity.
Given that the analysis conducted using ANFIS, with previously normalised values, does not exclude the simultaneous observation of GDP and GDP per capita, both variables were taken into consideration in this model to observe deviations in conclusions in relation to one and the other variable, or to show the suitability of each in future research on similar topics. The results of the analysis conducted using Model 5 are shown in Figure 14 in 3D and 2D formats.

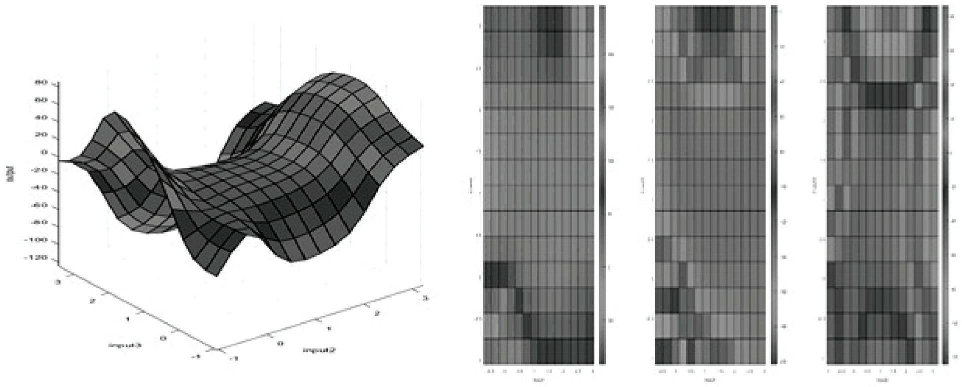

Figure 14. *Model 5 in 3D and 2D format*
Source: Systematization of the author in MATLAB according to Markuz (2022)

The analysis indicates that very low values of the GERD by performance sector parameter, together with very low values of the Gross Domestic Product at market prices parameter, contribute to very high energy productivity. In other words, energy productivity in the current conditions is achieved by countries with a low share in production and R&D. At the same time, a very high share of the GERD by performance sector parameter, together with a very high share of the GDP at market prices parameter, contributes to a low and negative level of energy productivity. Therefore, when investing in GERD by performance sector, in the context of energy productivity, more attention should be paid to sectors that currently achieve a high level of the GDP at market prices parameter and funds should be invested in those industrial or service branches that will contribute to energy productivity.
When analysing the relationship between the GERD by performance sector parameter and GDP per capita in the PPS (display of the relationship between Input 1 and Input 3), it is evident that only very high values of the GERD by performance sector parameter, along with medium and high values of the GDP per capita in the PPS parameter contribute to energy productivity that is not negative.

Similarly, very low values of the GERD by performance sector parameter, along with extremely low values of the GDP per capita in the PPS parameter contribute to extremely negative values of energy productivity.

Therefore, it can be concluded that the countries with higher GDP per capita also invest more and value more sector-oriented R&D, but also that there is a large disparity among the countries.

Very high energy productivity is suggested by the ratio of very low values of the Gross Domestic Product at market prices parameter, with simultaneous medium and high values of the GDP per capita in PPS parameter and (to a lesser extent) the ratio of very high values of the GDP at market prices parameter, with simultaneous medium and high values of the GDP per capita in PPS parameter.

The analysis with Model 5 suggests negative values for the medium values of the GDP at market prices parameter, with simultaneously very high values of the GDP per capita in PPS parameter, so countries with this combination of parameter values could serve as an example for further analysis of the selection or improvement of industrial policies in terms of energy productivity.

In conclusion, based on the obtained results and the analyses conducted in this section, hypothesis two is confirmed. Specifically, the evidence confirms that innovative, quality-based management of EE measures and efficient use of RES, supported by financing from the ESI Funds, contributes to a faster transition towards achieving the level of productivity and competitiveness of developed EU countries. Also, the function of sustainable development and strengthening of the resilience of Croatia is reflected in the results as follows:

- Energy efficiency in the context of economic productivity and growth, and in accordance with the EU guidelines and strategies, requires, first and foremost, a higher share of renewable energy in gross final consumption;
- The development of a single digital market, which is also one of the prerequisites for productivity, is directly dependent on the previously mentioned condition (high level of EE and high share of renewable energy in gross final consumption), and should be the driver of creating the need for a higher share of R&D personnel, which, on the other hand, should also encourage e-government activities among individuals;
- Policies of individual countries should therefore be able to direct the capabilities of the population in relation to digitalisation in a timely manner, while ensuring sufficient state budget funds, and focus R&D on recognising the potential of individuals and creating industrial policies based on this with the aim of achieving EE;
- There is a strong connection between social policy and investment policies in the desired level of employment in high and medium-high technology as a prerequisite for greater productivity and competitiveness and EE;
- Very high energy productivity is suggested by the appearance of medium and high values of GDP per capita;

- Regarding the criterion of R&D by sector of performance from which very high values are expected in terms of EE, but also productivity and competitiveness, it simultaneously requires very high values of the parameter ESIF spent.

Strong evidence of ESIF's key contribution to the implementation of measures to increase EE and the increased use of RES is found in the analysis conducted using Model 4, which links EE, electricity generation capacities and the value of spent ESIF. The key contribution of the ESIF, according to the analysis conducted, is reflected in the expected high values of electricity generation capacities and the required (at least) medium values of ESIF that were available to each country.

5. CONCLUSION

Based on the previously conducted and presented analyses in theoretical and applied terms, it is possible to propose an innovative methodological approach to support better decision-making by policymakers regarding EE, measured in the context of economic development. The basis of this methodological framework is the direct connection between EE and the parameter Share of renewable energy in gross final consumption. That is, as previously highlighted in the analytical part, better EE is achieved with medium and high values of the Share of renewable energy in gross final energy consumption parameter.

Croatia recorded low to medium values of the parameter Share of renewable energy in gross final consumption, and in the context of EE in terms of economic development, additional investments should be directed precisely to RES for this parameter to achieve medium to high values. According to the research conducted through a questionnaire, such conclusions are also supported by entrepreneurs, and 91% of them believe that they would invest in some of the measures related to EE and RES; they emphasised that they expect state assistance and EU funding in almost identical percentages on this path.

Better EE has so far been achieved with lower and medium values of the parameter R&D Personnel by performance sectors, and on this basis, it can be concluded that the performance sectors are key in further analyses of investments in R&D Personnel. In this regard, it should be noted that in Croatia the value of the parameter R&D Personnel by performance sectors is at a very low level and this is one of the priority areas in which additional investment should be made. The survey shows that entrepreneurs also agree with this, of whom 54% believe that investment in R&D is extremely important in terms of productivity and competitiveness, while 35% believe that this type of investment is important. Therefore, policies for allocating the EU funds in this context should be more focused on creating adequate R&D personnel and merging entrepreneurship and rehsearch institutions.

E-government activities of individuals via websites should be at very low levels and this is the case in Croatia. However, such analysis results may imply that funds have already been invested in the digitalisation of public administration and the assignment of such tasks to companies via outsourcing, which is not currently the case in Croatia, although it would be desirable. The analysis conducted based on a survey of entrepreneurs shows that only 33% of entrepreneurs are informed about the EU funds via the Internet and that the majority still rely on state institutions and consultants. In this regard, perhaps consultants could play a larger role through outsourcing within the state apparatus as a support for economic development.

This is also supported by the next parameter of interest, the Digital Single Market – promoting e-commerce for businesses, from which, according to the analysis conducted, medium and high values are expected. Croatia, in relation to this parameter, achieves medium values, but there is an evident need for additional investments in order for this parameter to reach high values. Only 25% of entrepreneurs recognised that investing in information and communication technologies is very important for the development of productivity and competitiveness; therefore, it is necessary to invest in raising awareness among entrepreneurs about the importance of applying such technologies, and sufficient funds need to be provided for this.

According to the analysis conducted in Model 2, Croatia does not require significant additional investments in EE in terms of economic development, as it achieves low to medium values of the Dependence on energy imports parameter, while at the same time achieving high values of the Individuals - Internet use parameter. The same applies to the combination of the Share of approved funds in the state budget or R&D expenditures and Individuals – Internet use parameters. Therefore, further necessary investments for R&D are expected to rely more heavily on the EU funds in this context, and it is precisely by investing in the right way, i.e., in the order as mentioned above, that it is possible to reduce dependence on energy imports and create a higher share of individuals using the Internet on the European market.

According to the analysis conducted in Model 3, Croatia has low values of the parameter Population that cannot heat their homes due to poverty. However, the analysis showed that these values should be very low, therefore, policies should focus on RES for the energy-poorer category of the population, with significant support from EU funds. The analysis also showed that very low values of the parameter Population that cannot heat their homes due to poverty are associated with very low values of the parameter Employment in medium-high and high technology, which indicates a still insufficient degree of transition to the desired industrial sectors within the EU (observed countries and observed period). The medium values of the parameter Employment in medium-high and high technology, which are expected in terms of EE in the context of economic development, stipulate a need to allocate larger investments, because the value of this parameter in the observed period is very low. In addition to the aforementioned, the analysis in Model 3 showed that the parameter Participation rate in education and training should take on medium values, and in Croatia they are also at a low level. This is also supported by the conducted analysis of the surveyed entrepreneurs, of whom 57% believe that continuous training of employees is extremely important in terms of productivity, and 31% of entrepreneurs consider this item important. In summary, as is evident from the conducted analyses, the transition to efficient energy management according to the EU guidelines should also be focused on the parameter Population that cannot sufficiently heat their homes due to poverty status, i.e., part of the gross added value should be allocated to EE in this context as well. The parameter Participation rate in education and training must be more focused on achieving digital skills and employment in high technology, as well as on training the population and raising awareness of business entities about the importance of EE itself through a more significant use of RES.

The analysis conducted based on Model 4 can be characterised as the most significant. Regarding the expectations of a very high value of the Energy Capacities parameter in combination with medium and high values of the GERD parameter according to the performance sector, Croatia, unfortunately, is in an extremely poor position. Namely, in both parameters mentioned above, Croatia achieved very low values in the observed period. Therefore, the targeting of policies and funds, especially those from the EU, should be maximally placed in these two areas. The aforementioned is also supported by the views of entrepreneurs, of whom as many as 42% think that in the coming short period there will be problems regarding the security of supply from conventional energy sources, and as many as 95% of them believe that energy prices will increase significantly in the next five years. Likewise, 82% of entrepreneurs believe that Croatia needs to invest significantly more in RES to reduce this dependence. The views of entrepreneurs on the need to invest in RDI are positive, i.e., 54% of them believe that such investments are extremely important, and 35% consider such investments important. If we talk about targeted or sectoral R&D, 66% of entrepreneurs consider investing in technologically advanced solutions to be extremely important, and 29% consider them important. The aforementioned needs to be achieved by using ESIF. Namely, the analysis also indicated the need for medium to high values of ESIF utilisation. Croatia, unfortunately, achieves very low values here as well. This is also indicated by the views of entrepreneurs, 90% of whom believe that the EU funding is extremely important in the context of competitiveness and productivity, but also EE and climate neutrality. The state administration should also contribute significantly here, because around 40% of entrepreneurs believe that there is an administrative obstacle to using ESIF.

To conclude, it is evident that the production capacities of individual countries are linked to the parameter Research and Development by performance sector and ESIF spent. Therefore, larger capacities for production of electricity from RES can contribute to a larger allocation for R&D (due to energy savings), which will ultimately enable better economic development. This is also linked to the analyses of the efficiency of the administration, which should be additionally directed and educated for the planning of tenders and their implementation (speed of action) to achieve the most efficient allocation of funds in the context of faster economic growth accompanied by EE measures.

The Model 5 analysis, which relates to energy productivity, highlighted the significance of the need for very high values of the GERD by performance sector parameter, along with medium and high values of GDP per capita. The position of Croatia in relation to GERD has already been highlighted previously. On the other hand, Croatia's GDP per capita in PPS is still at low levels, which indicates the need to implement all the policies already highlighted and to determine priority objectives and actions in this context.

To conclude, the investment priorities in the context of strengthening the Croatian economy through EE should, in line with the key findings of this research, be:

- Investing in efficient and fast administration focused on helping entrepreneurs and citizens, especially in terms of using the EU funds.
- Engaging a larger number of consultants to help entrepreneurs and citizens.
- Engaging a larger number of consultants to help entrepreneurs implement the research and development component.
- Strengthening research capacities that can contribute to the effective combination of science and entrepreneurship.
- Greater and faster investments in RES.
- Greater and faster investments in energy infrastructure in terms of energy productivity.
- Greater and timely investments in the availability of RES to the poor.
- Investing in free informal education aimed at raising awareness about the importance of digital technologies and modern technological solutions in business and the everyday lives of citizens.
- Creating an environment for employment in medium and high technology through effective 'industrial' strategies.

The paper argues that the innovative approach of this research is reflected in a new way of highlighting the essence of cohesion policy itself or the way in which individual countries should determine investment priorities, as well as the importance of simultaneously implementing individual policies, while previous research has mainly been focused on observing individual policies or objectives separately. In accordance with the aforementioned, the observed variables showed that despite their non-linearity, fuzzy logic made it possible to find interconnections for modelling innovative solutions to problems of uncertainty in the decision-making process. Therefore, the paper concludes that the classification of selected analysed variables of interest for improving the methodological framework resulted indeed in an improved methodological framework based on ANFIS analysis of variables' relationships. Moreover, it provides a new approach of enhancing sustainable economic growth in Croatia and thus enabling better decision-making when managing EE measures and increasing the use of RES for Croatia's economic development. By strengthening its strategic advantages and applying a new innovative governance model, which includes more careful planning of priorities, a more efficient and educated administration, larger and faster investment in renewable energy sources and research and development, Croatia can achieve faster and greater economic growth and welfare for its citizens.

However, some limitations within the framework of this research are reflected in the relatively small sample of entrepreneurs who responded to the questionnaire, the inconsistent methodology (changed in some years) for calculating RES, as well as the fact that only small economies were considered. Therefore, the recommendations for future research could consider a more significant inclusion of expert opinion, especially through entrepreneurs' surveys in larger economies and/or more developed countries and under changing political circumstances, where nonlinear causalities can be successfully detected and further analyses done using fuzzy logic, and ANFIS could provide valuable insight into economic development or lack thereof.

ACKNOWLEDGMENT

I extend my heartfelt gratitude to Prof. Sonja Brlečić Valčić of Zadar University, CRO, for her invaluable suggestions and recommendations during the preparation of this paper.

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NOVI PRISTUP POBOLJŠANJU ODRŽIVOG GOSPODARSKOG RASTA U HRVATSKOJ: ANFIS ANALIZA MEĐUDJELOVANJA VARIJABLI

Sažetak

Gospodarski rast počiva na ljudskom kapitalu, uz prirodne resurse, tehnološke inovacije i kapital, što ukazuje na snažnu međuovisnost između kvalitete učinkovitog upravljanja i proizvodnih inputa. Energetska učinkovitost je instrument za postizanje konkurentnosti i gospodarskog rasta. Dok obnovljivi izvori energije u energetskom miksu mogu smanjiti ovisnost o uvozu i neizvjesnost opskrbe energijom, kao i pomoći u dekarbonizaciji industrije, iskorištavanje sinergija između energetskih i industrijskih politika bit će ključno za postizanje konkurentnosti. Ovaj znanstveni rad istražuje modalitete poboljšanja upravljanja mjerama energetske učinkovitosti kroz analizu međuovisnosti odabranih varijabli i njihov utjecaj na promatrane izlazne varijable, energetsku učinkovitost i energetsku produktivnost. Novi pristup ukazuje na varijable koje treba uzeti u obzir pri odabiru smjera brže tranzicije i gospodarskog prosperiteta Hrvatske. Odabrane varijable imaju tendenciju biti nelinearne pa se neizrazita logika koristi za smanjenje nesigurnosti u donošenju odluka u prisutnosti takvih nelinearnosti. Prilagodljivi neuro-fuzzy sustav zaključivanja (ANFIS) primijenjen je za novi pristup u povezivanju takvih varijabli i davanju boljih rezultata modeliranja. Dodatno, stručno znanje uvedeno je kroz anketu hrvatskih poduzetnika, za potrebe validacije. Analiza međuovisnosti varijabli daje vrijedan uvid za buduće intervencije, a u zemljama članicama EU ukazuje na potrebu za drugačijim modelom učinkovitog upravljanja. U tom kontekstu konstruiran je poboljšani, optimalni model, koji može, ako se primijeni, pomoći Hrvatskoj u bržem gospodarskom rastu.

Ključne riječi: *adaptivni neuro-fuzzy sustav zaključivanja, energetska učinkovitost, Hrvatska, inovativni model upravljanja, održivi gospodarski razvoj*

EIN NEUER ANSATZ ZUR FÖRDERUNG EINES NACHHALTIGEN WIRTSCHAFTSWACHSTUMS IN KROATIEN: ANFIS-ANALYSE DER BEZIEHUNGEN ZWISCHEN INTERAKTIVEN VARIABLEN

Zusammenfassung

Wirtschaftswachstum beruht neben natürlichen Ressourcen, technologischer Innovation und Kapital auch auf Humankapital, was auf eine starke Wechselbeziehung zwischen der Qualität eines effektiven Managements und den Produktionsfaktoren hinweist. Energieeffizienz ist ein gutes Instrument, um Wettbewerbsfähigkeit und Wirtschaftswachstum zu erreichen. Während erneuerbare Energien im Energiemix die Importabhängigkeit und die Unsicherheit der Energieversorgung verringern und zur Dekarbonisierung der Industrie beitragen können, wird die Nutzung von Synergien zwischen Energie- und Industriepolitik entscheidend für die Erreichung von Wettbewerbsfähigkeit sein. Diese wissenschaftliche Arbeit untersucht Möglichkeiten zur Verbesserung des Managements von Energieeffizienzmaßnahmen durch eine Analyse der Wechselbeziehung ausgewählter Variablen und ihrer Auswirkungen auf die beobachteten Output-Variablen, Energieeffizienz und Energieproduktivität. Ein neuer Ansatz zeigte die Variablen auf, die bei der Wahl der Richtung für einen schnelleren Übergang und wirtschaftlichen Wohlstand Kroatiens berücksichtigt werden sollten. Die ausgewählten Variablen sind in der Regel nichtlinear, daher wird Fuzzylogik verwendet, um die Unsicherheit bei der Entscheidungsfindung bei solchen Nichtlinearitäten zu verringern. Das Adaptive Neuro-Fuzzy-Inferenzsystem (ANFIS) wurde für den neuen Ansatz eingesetzt, um solche Variablen miteinander zu verbinden und bessere Ergebnisse der Modellierung zu erzielen. Zusätzlich wurde

Expertenwissen durch eine Umfrage unter kroatischen Unternehmern zur Validierung herangezogen. Die Analyse der gegenseitigen Abhängigkeit von Variablen liefert wertvolle Erkenntnisse für künftige Maßnahmen und zeigt in den EU-Mitgliedstaaten die Notwendigkeit eines anderen Modells für eine wirksame Regierungsführung auf. In diesem Zusammenhang wird ein verbessertes, optimales Modell entwickelt, das Kroatien im Falle seiner Anwendung zu einem schnelleren Wirtschaftswachstum verhelfen kann.

Schlüsselwörter: *Adaptives Neuro-Fuzzy-Inferenzsystem, Kroatien, Energieeffizienz, innovatives Governance-Modell, nachhaltige wirtschaftliche Entwicklung*