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Important indicators within decision‑making process in sustainable energy transition

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Abstract. The sustainable energy transition of the country or groups of countries is a complex and long-term process that requires decision-making at several stages and levels, including the evaluation of a large number of factors. Presented paper deals with indicators that, together with certain World Bank indicators, can form a meaningful set useful for decision-makers in the context of a sustainable energy transition. The use of selected indicators is also recommended when evaluating the integration of economic-environmental content into an economic development planning. A part of data support for a sustainable energy transition is formed by indicators that include political-administrative, economic-social and environmental factors. The core of the mentioned data support is determined by the indicators of energy intensity and the share of energy from renewable sources in the gross final energy consumption. Both are influenced by a series of independent indicators. Number of indicators can be redundant in certain cases, so the appropriate number of them could be found with the procedure based on the role of entropy and the usage of correlation coefficients.

Key words. Sustainable energy transition, indicators, decision-making.

1. Introduction

Within sustainable transition studies, the topic of energy is becoming an important interdisciplinary field. There is an increasing attention to low-carbon and environmentally friendly transition within areas of economies and societies, as well. Surely, a decision-making processes based on innovative indicators is strongly related to the same areas. At the same time is recognized that policies need to be designed in line with country-specific conditions, while sustainability data are highly needed to accelerate the low-carbon transition. A part of data support for a sustainable energy transition is formed by indicators that include political-administrative, economic-social and environmental factors [1]-[3]. The core of the mentioned data support is determined by the target indicators [4]-[6]. In accordance with the plans set by the EU for a sustainable energy transition, the indicator of energy intensity or primary energy consumption per unit of gross domestic product (GDP) and the share of energy from renewable sources in the gross final energy consumption can be classified as more important target indicators [1]. Both indicators could be set as dependent indicators. They are influenced by a series of independent indicators, namely with a positive or negative impact in terms of correlation. The following have a positive impact on the target indicators:

A) Electricity price
B) GDP per capita
C) Government effectiveness
D) Rule of law
E) Control of corruption
F) Political stability

Negative impacts on the target indicators represent a major challenge for successful and timely realisation of the target indicators of the sustainable energy transition. The most frequently considered indicators with a negative impact in terms of a successful sustainable energy transition are the use of fossil fuels, energy dependency, final energy consumption and energy supply. The difference between the values of energy supply and final consumption is often high in the case of solid fuels, mainly because of the transformation, or the dominant conversion of fuels into electricity.

In presented paper, set as dependent indicators, or influenced by a series of independent indicators, namely with a positive or negative impact are presented for Slovenia case. Aforementioned, can form a meaningful set useful for decision-makers in the context of a sustainable energy transition. Additionally, the procedure based on the role of entropy and the usage of correlation coefficients is shown [7]-[9]. Basically, entropy is a thermodynamic quantity that systems exchange when they exchange heat. Within the reversible changes, entropy does not change, while within the irreversible changes, it increases. Basically, energy systems tend to increase their entropy. This thermodynamic concept can be effectively used to explain various phenomena in the natural sciences, economic activity and within the society. Using this concept in combination with the statistical relationship between different variables, we show that some redundant indicators could be even eliminated from the final decision-making process.

2. Indicators with positive and negative impact

The indicators of energy intensity and the share of energy from renewable sources in the gross final energy consumption are classified as target indicators [1]. Energy intensity (Fig. 1) decreases as energy efficiency improves. In Slovenia, energy intensity has decreased by 36% since 2000. The improvement in energy efficiency is also indicated by the drop in electricity consumption per GDP. From 2004 to 2020, Slovenia increased the share of energy from renewable sources (RES) by 6.6 percentage points (Fig. 2). With production resources within the country and using the mechanism of statistical transfer of renewable energy from other EU member states, in 2020 it reached a 25% share of energy from renewable sources in gross final energy consumption.

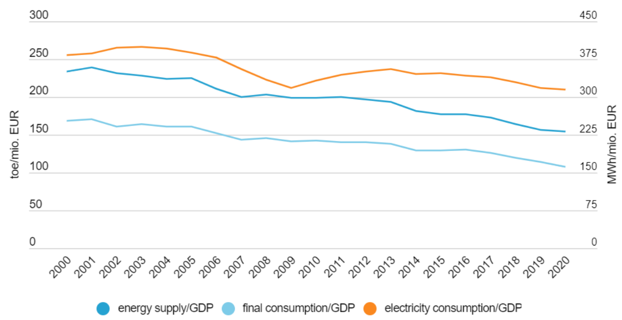

Fig. 1. Energy intensity per GDP in constant prices, reference year 2010 (Slovenia)

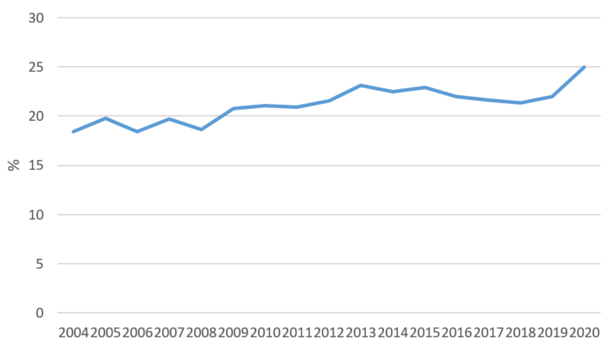

Fig. 2. Share of energy from renewable sources in gross final energy consumption (Slovenia)

Both indicators could be set as dependent indicators, influenced by a series of independent indicators, namely with a positive (electricity price, GDP per capita, government effectiveness, rule of law, control of corruption and political stability) or negative impact (usage of fossil fuels, final energy consumption, energy supply and energy dependency) in terms of correlation.

When evaluating the electricity price indicator, it is necessary to distinguish between non-household (Fig. 3) and household (Fig. 4) consumers as well as between the price items for electricity, network charges, contributions, excise duties and the final price for consumed electricity, which also includes value added tax. The final price (Slovenia) for non-household consumers in 2021 amounted to 71.7% of the final price of electricity for household consumers, which was an increase of 13.9 percentage points compared to the value from 2016.

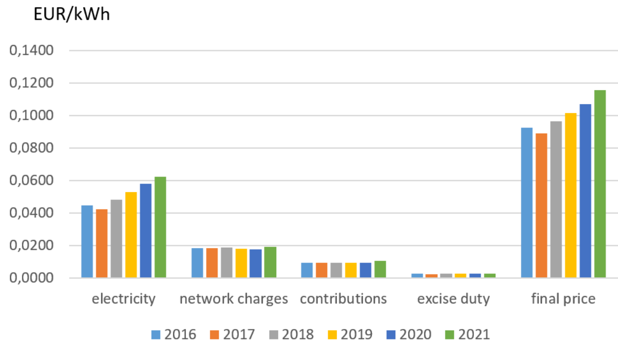

Fig. 3. Electricity price, non-household consumers (Slovenia)

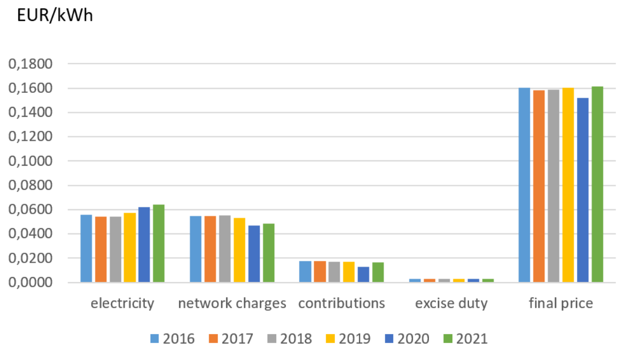

Fig. 4. Electricity price, household consumers (Slovenia)

The next indicator with a positive impact on the target indicators is GDP per capita (Fig. 5). A large increase is evident especially in the period up to 2008.

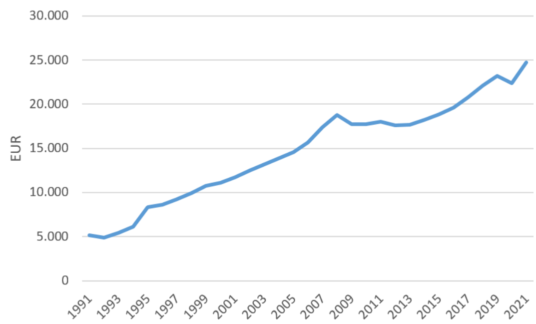

Fig. 5. Gross domestic product per capita (Slovenia)

In addition to environmental and economic factors, the EU strategy aimed at promoting sustainable economy also includes some institutional factors that include indicators of political stability, government effectiveness, rule of law and control of corruption. The World Bank [10] calculates the indicators for more than 200 countries and territories and evaluates them on a scale between −2.5 and +2.5. A higher value means a better quality of the institutional environment (Fig. 6).

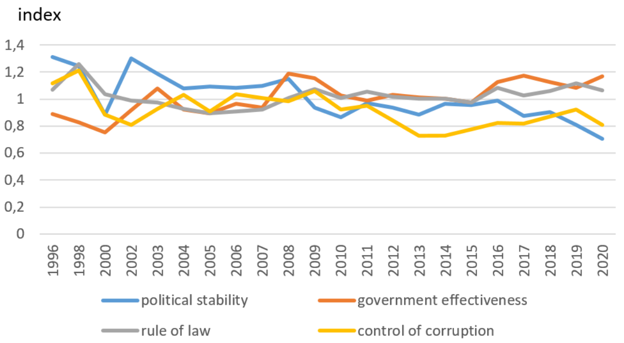

Fig. 6. Movement of quality indicators of the institutional environment (Slovenia)

Between 2008 and 2014, the use of petroleum products, natural gas and solid fuels in Slovenia has declined, both in the energy supply and in the final consumption (Figs. 7-9). It increased again between 2014 and 2018, which was followed by another decline. A similar finding can be made for the total energy supply and final consumption, where in 2020 Slovenia even reached a value lower than 200,000 TJ (Fig. 10).

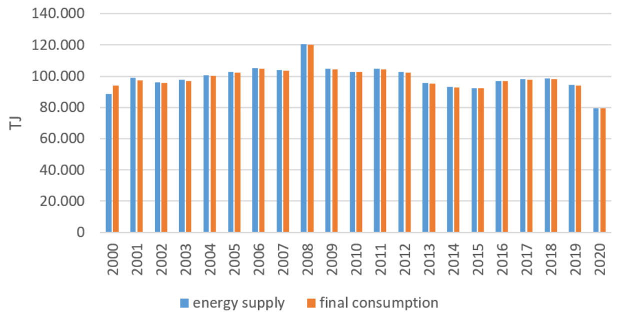

Fig. 7. Energy supply and final consumption, petroleum products, (Slovenia)

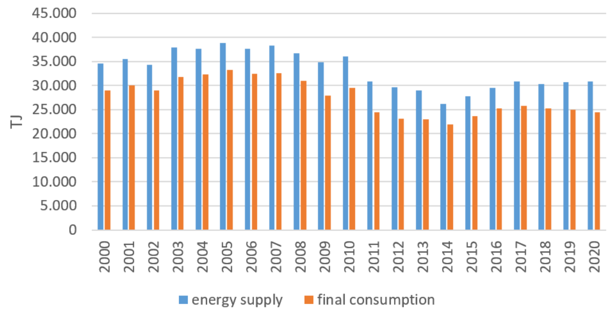

Fig. 8. Energy supply and final consumption, natural gas, (Slovenia)

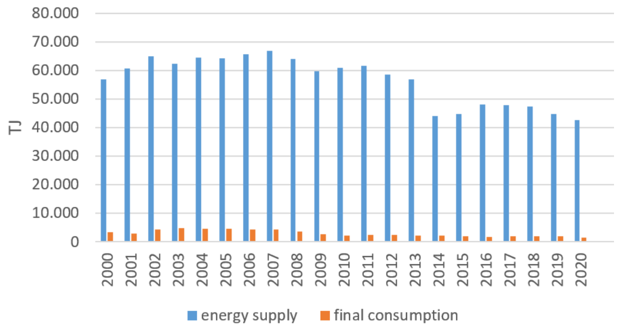

Fig. 9. Energy supply and final consumption, solid fuels, (Slovenia)

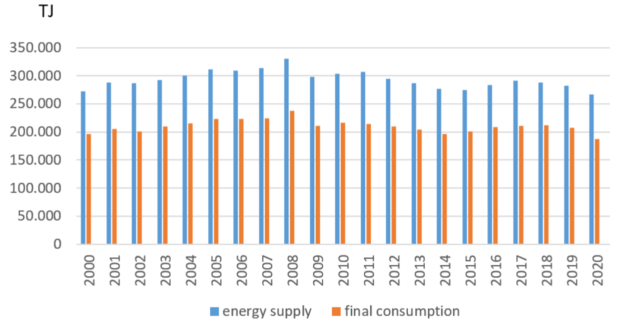

Fig. 10. Energy supply and final consumption, energy sources - total, (Slovenia)

Slovenia's energy dependency has not changed significantly since 2008. A decline below 50% was followed by an increase above 50% again in 2012 and between 2017 and 2019 (Fig. 11).

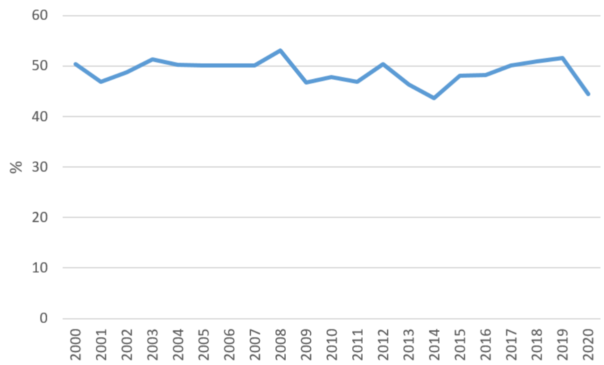

Fig. 11. Energy dependency (Slovenia)

3. Role of entropy

A closed system has only one source of entropy generation, namely the internal irreversible processes to which undergoes when it approaches the state of thermodynamic equilibrium. An open system, on the other hand, does not only have an internal component (S_{in}) for increasing entropy, but also an external component (S_{ext}) that is combined with matter and energy that are transferred to or from the environment. Thus, the entire increase of entropy in the system S, within the time interval, can be expressed by (1).

$$dS = dS_{in} + dS_{ext} \quad (1)$$

We can see that the sign of the expression for the internal entropy generation is evident. Namely, it is an entropy exchange that corresponds only to a closed system, i.e. it has a positive sign. The expression for the external generation of entropy can have a positive or negative sign, because it depends on whether the system brings entropy from the environment or transfers it into it.

The role of entropy could be explain within the energy dependency indicator. In the Fig. 12 energy dependency Ed_{obs} of observed (closed) system is presented together with energy dependencies of two neighbouring groups

Ed_x and Ed_y. Since first neighbouring group Ed_x presents much higher energy dependency in comparison to Ed_{obs} the system transfers entropy into the environment. In case of Ed_y it is so only in a few points, otherwise the flow of the entropy is opposite. So, in second case the original values of external component should be replaced with the values of Ed_y.

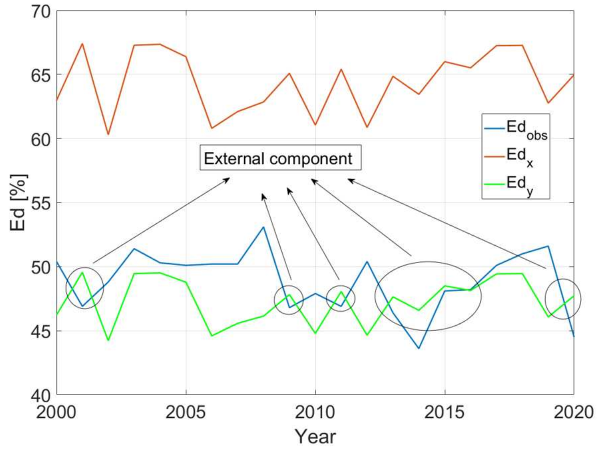

Fig. 12. The role of entropy within the energy dependency indicator

Finally is possible to calculate the correlation coefficient *Corr*, in sense of measuring how strong is a relationship between two variables. The procedure is presented by equations (2) – (7), where *A* and *B* stand for both variables, while *No* is the variable length. After the role of entropy is applied on whole set of indicators and the correlation coefficient procedure is dropped through the variables, results presented in Fig. 13 are obtained. Is it clear that correlation coefficient reach similar values for the number of indicators from 6 to 9. It is obvious that three indicators in our set are redundant and could be even eliminated from the final decision-making process.

$$X_A = \sum(A) \quad (2)$$

$$X_B = \sum(B) \quad (3)$$

$$X_{A2} = \sum(A.)^2 \quad (4)$$

$$X_{B2} = \sum(B.)^2 \quad (5)$$

$$X_{AB} = \sum(A.)(B) \quad (6)$$

$$Corr = \frac{(NoX_{AB} - (X_A X_B))}{(((NoX_{A2} - X_A{}^2)(NoX_{B2} - X_B{}^2))^{1/2})} \quad (7)$$

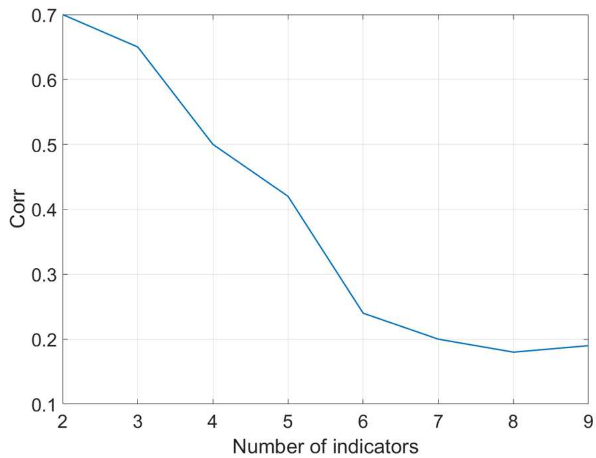

Fig. 13. The correlation coefficient for different number of indicators

4. Conclusion

Set of indicators, together with the used optimization methods and models, machine learning tools or methods of artificial neural networks, significantly contributes to the preliminary analyses of the transition to sustainable energy sources and the simultaneous sustainable management of energy. They represent the basis for a comprehensive discussion between policy-makers and decision-makers, researchers, industry representatives, civil society and other interested stakeholders, and the introduction of innovations within the process of sustainable energy transition. Within the paper a set of indicators that can form a meaningful set useful for decision-makers in the context of a sustainable energy transition is presented. All of the indicators are shown for the country of Slovenia. Additionally, the procedure based on the role of entropy and the usage of correlation coefficients is briefly presented. It is shown, that the number of indicators can be redundant in certain cases, so after the implementation of procedure some of them could be eliminated from the final decision-making process.

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