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HYBRID CRITIC-TOPSIS MODEL FOR PRIORITIZING DIGITALLY DEVELOPED COUNTRIES IN THE LIGHT OF ENERGY INDICATORS

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Abstract: Digital progress of the society is associated with trends in energetic sector. The top ten digitally developed European countries, according to the most recent ICT development index report in 2017, were chosen as testing countries to conduct a deeper investigation on the issue of energy production and consumption in the digital era. Data on (1, 2) coal and oil-fired electricity generation, (3) share of GHG emissions from energy production, (4) final electricity consumption in industry, (5) final electricity consumption in households, and (6) energy intensity were included in the initial database. For determining criteria weights and final ranking of alternatives, a hybrid CRITIC-TOPSIS MCDM model was utilized. The CRITIC approach was used to calculate objective weights of criteria by employing standard deviation to measure the contrast strength of each criterion. The findings highlight the dominance of three criteria in comparison to others: energy intensity (w_{ei} = 0.200), share of GHG emissions in total energy production (w_{eGHG} = 0.198), and ultimate energy consumption in households (w_{fch} = 0.194). The TOPSIS approach was used to complete the final ranking. Switzerland, Luxembourg, and Sweden were ranked first, second, and third, respectively, in terms of advanced digitalization performance and awareness of the need of providing green energy for economic activity.

Keywords: energy, digitalization, multi-criteria decision-making, CRITIC-TOPSIS

1. INTRODUCTION

Modern society is facing serious energy issues that tackle secure energy supply and renewable energy sources (Carrilho-Nunes & Catalão-Lopes, 2022). A number of countries have adopted the agreement to become carbon neutral until 2050 and now they implement different energy strategies and set ambitious energy targets (Jin, 2022). In order to fulfill the Paris Agreement by which global rise of temperature must be kept below 2℃, European Union has long term commitment to reduce GHG emission to become carbon neutral continent by the year 2050 while reducing the quantity of total GHG by 55% until 2030 (European Commission, 2020). Accelerated diffusion of industrial activity is the major contributor to the increased share of greenhouse gasses (Lin & Jia, 2020). In addition, industry intensity is associated with increased electrical energy demand (Li & Yuan, 2021). Active government's role in decreasing pollution caused by industrial sector is found in fostering the sustainability concept (Yue et al., 2021). Achieving sustainability in industrial

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sector is possible under developing the use of artificial intelligence technology in different spheres thus developing industry 4.0 (Liu et al., 2021). Implementing advanced technological solutions in industry force overall technological progress that in turn enhance energy consumption. In this way technology and industry are united in the same mission to mitigate the effects of climate change and prevent further environmental pollution. Technological progress enables the use of energy efficient technology that is a key to establish economic progression followed by rational energy consumption and future environmental degradation (Hui et al., 2021). It facilitates transition to low-carbon technological solutions thus reduces energy intensity (He et al., 2021).

The study's primary objective is to rank the top 10 digitally developed European countries in terms of energy production, consumption, and pollution from energy production. For that purpose multi-criteria decision making (MCDM) methodology has been applied since various energy parameters have been used for prioritization. CRITIC MCDM has been used to calculate the weights of energy attributes, while final prioritization is done using TOPSIS method.

Since digital technology is energy intensive, empirical evidence on its effects on energy balance is required to promote further digital development. As a result, the study's expected scientific contribution is to provide theoretical and practical understanding concerning energy balance in digitally advanced European countries. In addition, proposed methodological concept can be used to rank other countries according to their energy parameters or it can be used as a guide to solve similar prioritization problems. Empirical findings in this study are found to be valuable for decision makers in energy and technology sectors, as well as for future sustainable development of digitalization process. The research outcome can contribute to further comparative analysis with less digitally developed economies.

The following five sections constitute the study. The second section offers a brief overview of the current literature on energy balance and pollution in digitally developed countries. The study's empirical data and analytical methodology are described in Section 3. Section 4 highlights the most important study findings and provides a more in-depth discussion. Finally, section 5 summarizes the findings.

2. LITERATURE REVIEW

Digitalization brings prosperity to the society and economy. However, several studies have discovered increased GHG emissions due to accelerated technological diffusion (Carrilho-Nunes & Catalão-Lopes, 2022; Su & Fan, 2022). Authors Golroudbary et al. (2022) discussed ecological issue of developing green high-tech solutions whose development is constrained by depletion of valuable resources. High-tech development and production phases are not clean process and leave traces on environmental degradation. This triggering effect can be solved by reducing the use of fossil fuels and ensuring enough energy supply from renewables. Authors Dolge & Blumeranga (2021) argue that improvements in energy efficiency can lead to a higher reduction of GHG emissions than fostering renewable energy strategies. It is discovered that higher energy efficiency can contribute to energy transition towards sustainable and clean energy sources (Sun et al., 2022). However, contemporary studies (Yu et al., 2022) discover high energy intensity in economies with developed industrial sector that is major energy consumer. Particularly, the biggest emitter of GHG is acknowledged by manufacturing industry in those economies that have developed this industry sector (Zhang et al., 2020). Even if the share of renewables in developed economies is increasing at high rate, decrease in energy intensity is at much lower level. This phenomena is putting a lot of pressure on sustainable development of energy sector in the future and force economies to develop energy-saving technology in order to cut down electrical energy consumption (Yu et al., 2022). When faced with global challenges such as resource shortage and climate change, global economies struggle to provide adequate strategic answer in a form of green policies and strategies. Hence, innovation activities in renewable energy technology are desirable as they promote green development and serve to neutralize environmental pollution caused by increased industrial activities (Su & Fan, 2022).

EU strategy for becoming carbon neutral is based on liberating energy structure from fossil fuels, especially coal (Lehotský et al., 2019). EU has active Emission Trading System that is used to trace and control emissions generated by electrical energy production (Böhringer & Rosendahl, 2022). Even in some global countries, coal is still a critical source of fossil fuel that is used to generate electrical energy (Zhao et al., 2019; Schneider et al., 2020). Its role in delivering heating demand in many countries is still substantial making it as an important feature of national energy mix (Lin & Jia, 2020). Countries that own large coal reserves will struggle to eliminate the use of this conventional energy source because it is essential to secure future demand from clean energy sources and in the next stage to phase out fossil fuels (Zhao & Alexandroff, 2019). Another emerging challenge is the question of coal industry survival that slows down green energy transition. For example, powerful economies like China, Germany and Japan are outsourcing domestic coal production outside the national borders and orient their supply on foreign coal import rather than national production (Zhao & Alexandroff, 2019). Their ability to invest in cutting-edge technology in coal industry is higher than those of host countries therefore they transfer advanced technology outside the national borders. Global economies are constantly seeking for sustainable solution and propose the use of clean-coal technology for extracting that can ensure low-emission of GHG with improved efficiency (Zhao et al., 2019). While other economies are putting extra efforts to phase-out coal like in the case of Germany that has committed to eliminate coal use by 2038 in order to enhance its climate change goals (Keles & Yilmaz, 2020; Heinisch et al., 2021).

Consequences of climate change are present in all aspects of economy and society. Global warming is causing extremes in temperatures during summer and winter seasons. Therefore, population is facing rising temperature peaks that change the structure of energy demand in households (Zhang et al., 2022). Electricity demand in households is constrained by multiple factors such as life pattern of residents, however besides of all it includes facing extreme weather conditions (Andersen et al., 2017; Kang & Reiner, 2022). Household with increased number of cold days during winter season are prone to have increased electrical energy demand (Chen et al., 2022). The same situation is in countries where climate is hot during summer and additional electrical energy demand is directed towards cooling households (Tao et al., 2022). The process of digitalization tackles the energy demand of households by introducing IT appliances for home use on a large scale. Scholars reveal significant factor for evaluating electrical energy consumption in households that concerns the question of home IT appliances. Researches discover that as the number of owned IT devices increases and hours of usage, the demand for electrical energy is growing (Wallis et al., 2016). Authors Hao et al. (2022) discussed that current internet development has negative impact on energy intensity and in order to boost energy efficiency governments must invest in rising digital cities, digital cultures and societies.

3. RESEARCH DATA AND METHODOLOGY

3.1. RESEARCH DATA

The main research aim of this study is to rank ten European digitally developed countries by their energy balance that include energy demand, conventional energy consumption and environmental pollution that is a consequence of energy production from non-renewable sources. To rank the performances of these countries data about seven indicators that concern energy and digital indicators were collected. Summarized information about them can be found in the Table 1. Countries that are involved in the study include developed European economies such as Iceland, Switzerland, Denmark, United Kingdom, Netherlands, Norway, Luxembourg, Sweden, Germany and France that are ranked in the top of the latest ICT report for 2017. The listed countries are shown in descending order by their ICT development index from the most developed to the less digitally developed nations. Reference year for constructing MCDM decision matrix was 2018.

Table 1. Data structure

Criteria name	Label	Unit	Source
Electricity generation from coal	EGC	% of total electricity generation	Our World in data
Electricity generation from oil	EGO	% of total electricity generation	Our World in data
Share of GHG emissions $MTCO_2e$ from energy production in total GHG emission	eGHG	% of total GHG emission	Climate watch, 2022
Final electricity consumption - industry sector (TWh)	FCI	TWh	IEA, 2022
Final electricity consumption - other sectors household (TWh)	FCH	TWh	IEA, 2022
Energy intensity	EI	kWh/ GDP PPP	Our world in data, 2022
ICT Development Index (IDI)	IDI	Coefficient	Telecommunication Development Sector (ITU-D)

The research study is planned to be conducted into four phases illustrated in the Fig. 1. Selected analytic approach consists of a hybrid multi-criteria decision-making model composed of two methods. The first MCDM method is used for computing criteria's importance weight. This method is known as CRITIC method and it is often used method for determining importance weights in the objective mode. The second MCDM method used for final ranking is based on TOPSIS methodology. Proposed CRITIC-TOPSIS model requires constructing initial decision-making matrix that is established using gathered data.

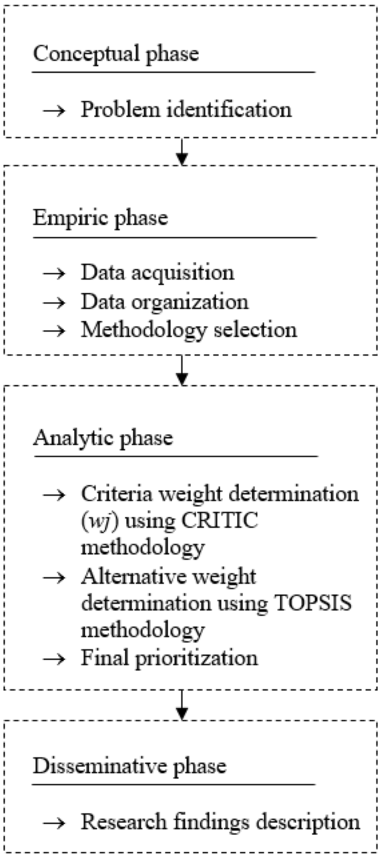

Fig. 1. Adopted research phases

Theoretical background about employed MCDM methodology can be found in the following part of the paper.

3.2. CRITIC METHOD

The Criteria Importance Through Intercriteria Correlation (CRITIC) method is a multi-criteria decision-making method for determining objective weights of criteria based on the comparative intensity of the evaluation criteria and conflict between them (Pan et al., 2021). Criterion with higher comparative intensity computed by formula for standard deviation is given a higher importance weight (Krishnan et al., 2021). By Diakoulaki et al. (1995) CRITIC method is preferable to use in situations to:

- Define objective weights when decision maker is inconsistent;
- Make it easier for decision maker to express opinion about the importance of criteria;
- Reduce subjectivity;
- Discard non-silent attributes.

Computation procedure for CRITIC methodology by Diakoulaki et al. (1995) is follow:

Step 1. Normalize the initial decision making matrix using formula:

For beneficial criteria:

$$x_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}}, \qquad i = 1,2, \dots, n; \qquad j = 1,2, \dots, m; \qquad (1)$$

For cost criteria:

$$x_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}}, \qquad i = 1,2, \dots, n; \qquad j = 1,2, \dots, m; \qquad (2)$$

where $x_j^{max} = {}^{max}_{j} \{x_{1j}, x_{2j}, \dots, x_{mj}\}$ and $x_j^{min} = {}^{min}_{j} \{x_{1j}, x_{2j}, \dots, x_{mj}\}$.

Step 2. Compute standard deviation σ_j for each criterion.

Step 3. Form symmetric matrix.

Step 4. Determine the quantity of the information in relation to each criterion.

$$w_j = \sigma_j \sum_{k=1}^{n} (1 - l_{kj}) \qquad (3)$$

Step 5. Normalize w_j measure of criteria.

$$w_j = \frac{w_j}{\sum_{k=1}^{m} w_k} \qquad (4)$$

Step 6. Compute objective weights of each criterion.

$$w_j = \frac{\sigma_j}{\sum_{k=1}^{m} \sigma_k} \qquad (5)$$

3.3. TOPSIS METHOD

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision-making methodology that was introduced by Hwang and Yoon in 1981 (Hwang & Yoon, 1981). Through its application, original TOPSIS method has gained some novelty modifications and extensions (Ren et al., 2007). The basic idea behind the TOPSIS method is to prioritize alternatives is such order that the best alternative is the one closest to the positive ideal solution, and the worst alternative is the one closest to the negative ideal solution (Krohling & Pacheco, 2015). Positive ideal solution is maximizing benefit criteria while minimizing cost criteria and negative ideal solution is determining opposite solution (maximize the cost criteria while minimize benefit criteria) (Behzadian et al., 2012). The distance between solutions can be computed using several metrics but the commonly used is Euclidian norm based on the minimization of square root of the sum of squared distances (Olson, 2004). Other possible distance metrics consider least absolute value terms or minimum maximum distance difference. The subjectivity in applying this method is reduced to minimum and it is introduced when inputting the data about criteria weights (Olson, 2004).

TOPSIS computation procedure by Hwang & Yoon (1981) is given as follow:

Step 1. Form normalized decision matrix

$$r_{ij} = x_{ij} / \sqrt{(\sum x_{ij}^2)} \quad \text{for} \quad i = 1, \dots, m;\ j = 1, \dots, n; \tag{6}$$

where x_{ij} and r_{ij} are original and normalized values of formed normalized matrix.
Step 2. Form weighted normalized decision matrix

$$v_{ij} = w_j r_{ij} \tag{7}$$

where w_j is the weight for criterion j.
Step 3. Compute positive ideal and negative ideal solutions
For positive ideal solution:

$$A^+ = \{v_1^+, \dots, v_n^+\} \tag{8}$$
$$v_j^+ = \{\max(v_{ij})\ if\ j \in J;\ \min(v_{ij})\ if\ j \in J'$$

For negative ideal solution:

$$A^- = \{v_1^-, \dots, v_n^-\} \tag{9}$$
$$v_j^- = \{\min(v_{ij})\ if\ j \in J;\ \max(v_{ij})\ if\ j \in J'$$

Step 4. Compute the distance measure using Euclidian method
For positive ideal solution:

$$S_i^+ = \left[\sum (v_j^+ - v_{ij})^2\right]^{1/2} \quad i = 1, \dots, m; \tag{10}$$

For negative ideal solution:

$$S_i^- = \left[\sum (v_j^- - v_{ij})^2\right]^{1/2} \quad i = 1, \dots, m; \tag{11}$$

Step 5. Compute proximity to ideal solution and rang alternatives

$$C_i^* = S_i^- / (S_i^+ + S_i^-) \tag{12}$$

where 0 < Ci* < 1. The best alternative is closest to the value 1.

4. RESEARCH RESULTS

Hierarchical structure of prioritization model for ranking digitally developed countries according to energy criteria is based on following six criteria: electricity generation from coal (EGC), electricity generation from oil (EGO), greenhouse gas emissions from energy production (eGHG), final energy consumption in industry (FCI), final energy consumption in households (FCH) and energy intensity (EI). The model is considering 10 alternatives (A_1-A_{10}) presented in the form of countries that are the subject of prioritization. Alternatives are given in the descending value of IDI coefficient and include Iceland (A_1), Switzerland (A_2), Denmark (A_3), United Kingdom (A_4), Netherlands (A_5), Norway (A_6), Luxembourg (A_7), Sweden (A_8), Germany (A_9) and France (A_{10}). In order to compare diverse criteria CRITIC method for computing objective criteria weights has been used. All of the considered criteria are susceptible to minimize their effects on the prioritization goal therefore are classified as non-beneficial criteria and their impact is anticipated with decreasing utility function. Initial step in applying CRITIC method is to normalize the initial decision matrix. The results of the normalization procedure are presented in the following matrix r_{ij} with normalized values.

$$r_{ij} = \begin{bmatrix} 1.000 & 1.000 & 1.000 & 0.945 & 1.000 & 0.000 \\ 1.000 & 0.974 & 0.867 & 0.937 & 0.886 & 1.000 \\ 0.398 & 0.958 & 0.534 & 0.976 & 0.944 & 0.963 \\ 0.858 & 0.690 & 0.543 & 0.600 & 0.346 & 0.922 \\ 0.326 & 0.733 & 0.331 & 0.856 & 0.861 & 0.830 \\ 0.999 & 0.968 & 0.000 & 0.807 & 0.753 & 0.836 \\ 1.000 & 0.997 & 0.954 & 1.000 & 0.999 & 0.796 \\ 0.994 & 0.872 & 0.458 & 0.791 & 0.723 & 0.803 \\ 0.000 & 0.000 & 0.244 & 0.000 & 0.201 & 0.897 \\ 0.960 & 0.548 & 0.677 & 0.499 & 0.000 & 0.868 \end{bmatrix}$$

The next step is to apply formula for computing value of standard deviation within each criterion. Standard deviation is calculated in order to measure the discrepancies in the normalized values of criteria. The results are given in the following matrix σ.

$$\sigma = [0.3699\ 0.3127\ 0.3222\ 0.3072\ 0.3589\ 0.2861]$$

Next step is to calculate the symmetric matrix in $n \times n$ form that is used to identify linear correlation coefficient between criteria. In the next stage, the result of the symmetric matrix is utilized to calculate the measure of the conflict caused by each criterion in relation to other criteria. The quantity of information in respect to each criteria is determined by multiplying the standard deviation for each criteria with the measure of the conflict. The CRITIC technique uses the value of the quantity of information to compute the final objective weights. The following matrix w_j shows the final weights of the criteria.

$$w_j = \begin{bmatrix} 0.160 \\ 0.094 \\ 0.198 \\ 0.154 \\ 0.194 \\ 0.200 \end{bmatrix}$$

Matrix W_j reports criteria final energy consumption in households (W_{FCH}= 0.200), greenhouse gas emissions from energy production (W_{eGHG}= 0.198) and energy intensity (W_{EI}= 0.194) as most important for the prioritization procedure. Calculated objective weights are derived from CRITIC method and are further employed in the initial TOPSIS decision matrix.

First step in applying TOPSIS method is for final ranking of alternatives/countries in relation to criteria is to normalize initial decision matrix to r_{ij}. After normalizing the values in the decision matrix the next phase is to allocate appropriate criteria objective weights that are computed using CRITIC method. The results of the weighted decision matrix v_{ij} are presented as follow:

$$v_{ij} = \begin{bmatrix} 0.000 & 0.000 & 0.000 & 0.008 & 0.001 & 0.160 \\ 0.000 & 0.002 & 0.016 & 0.009 & 0.015 & 0.023 \\ 0.071 & 0.003 & 0.054 & 0.005 & 0.008 & 0.028 \\ 0.017 & 0.025 & 0.053 & 0.050 & 0.085 & 0.033 \\ 0.080 & 0.021 & 0.078 & 0.019 & 0.019 & 0.046 \\ 0.000 & 0.003 & 0.117 & 0.025 & 0.032 & 0.045 \\ 0.000 & 0.000 & 0.005 & 0.002 & 0.001 & 0.051 \\ 0.001 & 0.010 & 0.063 & 0.027 & 0.036 & 0.050 \\ 0.118 & 0.080 & 0.088 & 0.123 & 0.103 & 0.037 \\ 0.005 & 0.036 & 0.038 & 0.063 & 0.129 & 0.041 \end{bmatrix}$$

The next step is to calculate the measure of distance between each alternative and its ideal positive S_i^+ and ideal negative solution S_i^- using n-dimensional Euclidean distance. The results of matrix S_i^+ and matrix S_i^- generate the relative proximity to the ideal solution in the form of matrix C_i^* that denotes the outcome of the final prioritization of alternatives A_1-A_{10}:

$$C_i^* = \begin{bmatrix} 0.647 \\ 0.923 \\ 0.728 \\ 0.636 \\ 0.653 \\ 0.645 \\ 0.906 \\ 0.734 \\ 0.358 \\ 0.564 \end{bmatrix}$$

Table 2 reports results of the CRITIC-TOPSIS prioritization model with final ranking scores. The outcome of prioritization illustrates decisive advantage of Switzerland (C_2^* =0.923) and Luxembourg (C_7^* =0.906) compared to other countries. While the rest of the countries report approximately similar ranking scores, except Germany that is at the bottom of the ranking list (C_9^* =0.358).

Table 2. Final prioritization by hybrid CRITIC-TOPSIS model.

Country	Name	C_i^*	Rank
Iceland	A_1	0.647	5
Switzerland	A_2	0.923	1
Denmark	A_3	0.728	4
United Kingdom	A_4	0.636	7
Netherlands	A_5	0.635	8
Norway	A_6	0.645	6
Luxembourg	A_7	0.906	2
Sweden	A_8	0.734	3
Germany	A_9	0.358	10
France	A_{10}	0.564	9

TOPSIS method emphasize the importance of declining electricity generation from conventional energy sources (in this case, coal and oil energy sources) in countries like Germany and Netherlands. Germany is providing a third of total electricity generation from coal and a quarter from oil sources. While share of coal sources for electricity production in Netherlands reaches almost 25%. Germany and Netherlands are recognized as coal-intensive economies with substantial share of electrical energy production from coal resources (Yue et al., 2021). Countries with coal reserves distinguish this energy resource as integral part of energy mix while simultaneously work on improving efficiency of technology for coal processing (Zhao et al., 2019). Germany as the largest coal producer in the EU has adopted strategy to cancel emission allowances in order to eliminate coal use in the national energy mix (Böhringer & Rosendahl, 2022). On the other side, empirical evidence suggest Iceland, Luxembourg, Switzerland and Norway as leaders in using alternative energy sources for supplying electrical energy demand. Iceland is the only digitally developed country that satisfies total electrical energy demand from renewable energy sources therefore produce zero

GHG emission for this activity (United Nations, 2015). Similar results are achieved in Luxembourg that reports extremely low share of GHG emissions from electrical energy generation in total energy production. Obtained result is a consequence of import-oriented energy policy where more than 85% of electrical energy supply is secured from abroad (IEA, 2020). Further results distinguish Germany as digitalized economy with high GHG emissions from electrical energy production. In this case, Germany can be recognized as highly industrialized economy with substantial share of energy sources from fossil fuels therefore the GHG emissions that pollute the environment are higher. Countries that are highly industrialized and dependent on the use of coal should introduce sustainability in the industrial sector and promote energy-efficiency for industrial activities (Yue et al., 2021). Empirical evidence confirm intensified consumption of electrical energy sources for industrial sector in Germany, France and UK. While minimal electricity consumption for industrial needs are recorded in Luxembourg, Denmark, Iceland and Switzerland. The outcome can be supported by deficiency of industrial sector. Leaders in electricity consumption for household’s activities are Scandinavian countries Norway and Sweden. Taking in consideration that Norway and Sweden are known by extremely low temperatures in winter the consumption of electrical energy is predominantly used for needs of heating demand. The results are identical to a recent research by Chen et al. (2022) who confirm increased electrical energy demand in households that face extreme climate conditions. Khosravi et al. (2020) discussed that cold Scandinavian winters require large share of energy demand for heating purposes. Securing heat supply from renewable energy sources provides room for reducing energy intensity (Jin, 2022). Finally, by looking at the ratio of electrical energy consumption in comparison to available GDP, Iceland stands out as the most energy intensive economy, followed by Luxembourg, Sweden, Netherlands and Norway. The case of Iceland is specific because it is the result of several interconnected factors such as accessible low-cost electrical energy, industrial activities mostly related to metal industry and extreme weather conditions that include long and dark winters (Nordic Energy Research, 2013). Dolge & Blumberga (2021) found that decrease in energy intensity leads to decline in GHG emissions therefore economies that intend to achieve sustainability have to plan their strategies for improving energy intensity. The least energy intensive economy that is observed in this case is Switzerland. IEA (2022) puts Switzerland on the top of low-energy intensive economy thanks to the decarbonized energy sector that depend on nuclear and hydro electricity generation.

5. CONCLUSION

Over the years, the consumption of electricity for the needs of industry and households is constantly growing. Advanced technologies in the 4.0 industry that surrounds us require an increased intensity of spending this resource. As a result, the growth of digitalization, which is at the heart of Industry 4.0, is accompanied by a rise in energy consumption. Digital technologies are being used increasingly extensively not only in industry, but also in households, which now have an abundance of smart devices. As a result of this circumstance, society is progressing toward a modern way of life and modern communities. However, as technology progresses, so does the use of specific resources, and it's critical to analyze if these resources are being sustainably used.

As a result, the study's major goal is to show how to manage energy resources by using the example of highly digitalized European countries. The study that was carried out with this motive incorporated multi-criteria decision-making methodologies. For country prioritization, a hybrid CRITIC-TOPSIS framework was designed. The weighting elements of the criteria on which the prioritizing of alternatives was performed were computed using the CRITIC approach. Energy indicators for non-renewable energy production, electricity consumption in the industrial and home sectors, GHG emissions generated by electricity production, and energy consumption intensity are among the criteria. The most influential criteria for ranking, according to the results of the CRITIC technique, were final energy consumption in households, greenhouse gas emissions from energy production, and energy intensity. The TOPSIS approach was then used to prioritize the countries based on established criteria and weighting considerations. The prioritization results placed Switzerland and Luxembourg at the very top of the priority list. France and Germany are at the bottom of the rankings. Because industrial activity in France and Germany is significantly more intense than in the countries at the top of the list, such findings are partly expected. These sectors are drawing high electricity use and, as a result, a higher share of GHG emissions. According to the findings, countries with a higher ICT index score are ranked higher in terms of the considered indicators than those with a lower score. According to the ICT index, Iceland and Switzerland rank first and second, respectively, while Germany and France rank last.

According to the research, digitally developed countries, which are also industrial giants, must place more emphasis into enhancing renewable energy production. They must establish mechanisms for efficient energy generation and usage in order to reach this aim. Strong industrial activity that boosts their economic and social development must be directed towards low-energy intensive activities and low-carbon technology. Future development in such countries must be grounded on Industry 4.0, as well as a broader use of digital technology. In this regard, digitally developed countries should assist continued digital expansion by providing renewable energy solutions. Cutting-edge technology development must be based on zero GHG emissions. Only in this manner can long-term growth be maintained.

A number of shortcomings have been identified in the study. Only a few countries are included in the study. The study's scope is confined to nations with a high level of digital development, leaving theoretical and empirical gaps for countries with lower levels of digital development. Furthermore, because the reference year for the ICT report is 2017, there may be data discrepancies. Future studies should focus on other countries and include the most up-to-date statistics on digital advancement.

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