ENVIRONMENTAL RESEARCH
COMMUNICATIONS

PAPER • OPEN ACCESS

Prioritizing the indicators of energy performance management: a novel fuzzy decision-making approach for G7 service industries

To cite this article: Serhat Yüksel *et al* 2024 *Environ. Res. Commun.* **6** 015003

IOP Publishing Environ. Res. Commun. 6 (2024) 015003 https://doi.org/10.1088/2515-7620/ad1c07

Environmental Research Communications

OPEN ACCESS

RECEIVED
14 August 2023

REVISED
11 December 2023

ACCEPTED FOR PUBLICATION
8 January 2024

PUBLISHED
19 January 2024

PAPER

Prioritizing the indicators of energy performance management: a novel fuzzy decision-making approach for G7 service industries

Serhat Yüksel[1,2,3], **Serkan Eti**[4], **Hasan Dinçer**[1,3,*], **Yaşar Gökalp**[5], **Duygu Yavuz**[1], **Alexey Mikhaylov**[6,*] **and Gabor Pinter**[7,*]

[1] The School of Business, İstanbul Medipol University, Turkey
[2] Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon
[3] Clinic of Economics, Azerbaijan State University of Economics, Baku, Azerbaijan
[4] Vocational School, İstanbul Medipol University, Turkey
[5] The School of Health, İstanbul Medipol University, Turkey
[6] Financial University under the Government of the Russian Federation, Moscow, Russia
[7] Faculty of Engineering, Soós Ernő, Research and Development Center, Renewable Energy Research Group, University of Pannonia, Veszprém, 8200, Hungary
[*] Author to whom any correspondence should be addressed.

E-mail: serhatyuksel@medipol.edu.tr, seti@medipol.edu.tr, hdincer@medipol.edu.tr, ygokalp@medipol.edu.tr, duygu.yavuz@medipol.edu.tr, alexeyfa@ya.ru **and** pinter.gabor@pen.uni-pannon.hu

Keywords: energy efficiency, green building, ISO, performance management

Abstract

Ensuring energy performance management is important in many ways, such improvement of energy efficiency and decrease of energy costs are reduced. There are various indicators of the effectiveness of energy performance management of buildings. Due to this situation, businesses need to make the necessary improvements for the development of these factors. Nonetheless, these actions cause an increase in the costs of the companies. Hence, among these actions, the more important ones need to be identified. Owing to this issue, businesses can use their limited budgets for more priority indicators. The purpose of this study is to evaluate the main indicators of energy performance management systems. In this way, a new model is proposed to make a priority analysis for the hospitals. Firstly, five indicators of energy performance management systems are selected by considering ISO 50006 standards. Furthermore, these indicators are weighted by using Spherical fuzzy CRITIC. Secondly, G7 countries are examined with fuzzy RATGOS technique. Identification of the most significant indicators of the energy performance systems is an important novelty of this study. The most significant methodological novelty of this study is proposing a new technique to the literature named RATGOS. It is understood that energy efficiency is the most crucial indicator of energy performance management. Furthermore, it is also identified that France is the most successful G7 economy with respect to the energy performance management. Japan and United States have also high performance in this respect. It is recommended that necessary actions should be taken to increase energy efficiency. By conducting an energy audit, energy consumption data is analyzed so that energy losses and inefficiencies can be detected. This assessment provides opportunities for energy efficiency and helps identify improvement strategies.

1. Introduction

Energy performance management is a process used to monitor, evaluate, analyze, and improve the energy efficiency of a building or an organization. This process includes data collection, analysis, planning and implementation steps to manage energy consumption and energy performance. In this context, firstly, data on energy consumption and energy efficiency are collected (Karunanithi *et al* 2023). After that, the collected data is analyzed and performance indicators such as energy consumption, energy costs, energy efficiency indicators are calculated. This analysis is important for understanding energy use, identifying energy efficiency opportunities, and identifying weak spots. Based on the analysis results, energy performance targets are determined (Hakimi *et al* 2023). These goals may include reducing energy consumption, improving energy efficiency, and promoting sustainable energy use. Next, planned energy performance improvement steps are implemented. After the application, it is necessary to monitor and measure the energy performance (Kapp *et al* 2022). This situation allows to evaluate whether the determined targets have been achieved, to evaluate the effect of the improvements made and to take corrective measures if necessary.

Ensuring energy performance management is important in many ways. Energy performance management saves energy through monitoring, analysis, and improvement of energy consumption. Thanks to energy efficiency measures and strategies, energy resources are used more effectively, and energy costs are reduced (Ferrari *et al* 2023). In addition, energy performance management provides cost savings by increasing energy efficiency and reducing energy consumption. Less energy consumption means lower energy bills and significant savings in operating and usage costs. Energy performance management supports environmental sustainability by optimizing energy consumption. Energy saving reduces greenhouse gas emissions and ensures a more sustainable use of natural resources (Paramati *et al* 2022). This situation can minimize the negative effects on the environment. Energy performance management helps businesses monitor and improve their energy performance. More efficient use of energy ensures more reliable operation of energy systems, increases business continuity, and increases the competitiveness of the enterprise (Kostis *et al* (2022).

Different factors can affect energy performance management. Energy efficiency ensures that energy resources are used more effectively, which means energy savings. Less energy consumption reduces energy costs and ensures that energy sources can be used for a longer period (Paris *et al* 2022). System quality is very important for ensuring energy performance management. Accurate and reliable data is needed for energy performance management (Koutsandreas *et al* 2022). Energy consumption, energy costs and other performance indicators must be accurately measured and recorded. Quality systems reliably perform data collection, automation, and measurement, ensuring the precision and accuracy of data. To ensure energy performance management, effective legal regulations should also be provided (Zakari *et al* 2022). Energy performance regulations help set energy efficiency standards and targets. These standards and targets encourage buildings and organizations to achieve a certain level of energy efficiency (Alwaelya *et al* 2021, Mutalimov *et al* 2021).

There are many variables that have an important role on the effectiveness of energy performance management of buildings. In this context, to improve this performance, businesses need to make the necessary improvements for the development of these factors. However, these improvements also lead to an increase in the costs of the enterprises. In other words, if businesses carry out these improvement practices unplanned, this causes the costs to reach an uncontrollable level. Therefore, among these actions, the more important ones need to be determined. In this way, businesses will be able to use their limited budgets for more priority issues. This will also help increase productivity so that energy performance management should be improved without having high amount costs.

Accordingly, in this study, it is aimed to evaluate the main indicators of energy performance management system. In this way, a novel model is developed to make a priority analysis for the hospitals. In the first stage, five indicators of energy performance management system are identified by considering ISO 50006 standards. Moreover, these indicators are evaluated by using Spherical fuzzy CRITIC. In the second part of the proposed model, G7 countries are examined with fuzzy RATGOS technique.

Identifying the critical items for more effective energy performance management is a very difficult issue. Because of this situation, a comprehensive fuzzy decision-making model should be generated. However, existing models in the literature are criticized due to some reasons. The main drawback of these models is related to the uncertainty in this process (Alshamrani *et al* 2023, Majumder *et al* 2023). For example, the Euclidian distance is considered in the evaluations made by TOPSIS approach (Krishankumar and Ecer 2023). In this process, the distance to both positive and negative ideal results is used in the TOPSIS method (Corrente and Tasiou 2023). However, it is claimed that using the Euclidian distance is not correct to calculate the negative ideal result (Deng and Chen 2022). When these issues are taken into consideration, it is seen that a novel model should be created with a new ranking technique. Therefore, the main motivation in this study is to find the most significant variables of energy performance management via an original decision-making model in which a new ranking technique (RATGOS) is proposed.

The main contributions of the manuscript are explained as follows.

(i) Identification of the most significant indicators of the energy performance systems is an important novelty of this study. Different variables may have an influence on the performance of these systems. However, making improvements to these indicators leads to an increase in the costs of the companies (Manfren *et al* 2022). Hence, to prevent having too many costs, the more important indicators need to be determined. With the help of this issue, companies can use their limited budgets for more priority issues.

(ii) Making an evaluation for G7 countries also provides some advantages. G7 countries hold a crucial position in the global economy and are also responsible for a substantial proportion of the total greenhouse gas emissions across the globe. Consequently, these nations bear a heightened obligation to address environmental concerns. In these nations, a significant amount of energy is consumed by hospitals and buildings (Andersson and Thollander 2019).

(iii) The most significant methodological novelty of this study is proposing a new technique to the literature named RATGOS. Because of the criticisms to the currently ranking techniques in the literature, a new ranking technique (RATGOS) is created in this study. The geometric mean is used in the calculation process of the RATGOS. Hence, it is aimed to reach more effective solutions and minimize uncertainties in this process.

(iv) There are some advantages of using the CRITIC technique for weighting criteria. The main advantage of the CRITIC method is that it determines the objective criteria weights that include the contrast and conflict density in the structure of the decision problem (Amin *et al* 2022). Another advantage of the CRITIC method is that it normalizes the decision matrix by considering the ideal values of the cost and benefit criteria at the same time (Haktanır and Kahraman 2022). To make an effective priority analysis for the variables affecting energy performance management, the relationship between these factors should also be taken into consideration (Krishankumar *et al* 2022). Therefore, it seems that the CRITIC method, which uses the correlation relationship between the factors in the analysis process, is ideal for this study (Liu *et al* 2022).

(v) Selecting the indicators based on ISO 50006 standards also provides some advantages. ISO 50006 are international standards considered for energy performance management. These standards provide organizations with a framework for evaluating, improving, and tracking their energy performance (Fichera *et al* 2020). ISO 50006 provides a methodology and guidance for evaluating energy performance. Organizations can use this standard to objectively measure and analyze energy performance (Andersson *et al* 2021). Performance evaluation helps to identify critical indicators such as energy consumption, energy intensity, energy saving potential and to monitor performance. ISO 50006 provides guidance for improving energy performance (Batlle *et al* 2020). The standard provides a process for identifying, implementing, and monitoring energy efficiency measures. Organizations help to effectively manage energy saving projects and improvement activities.

(vi) Evaluating hospitals is another important contribution of this study. Hospitals have great potential in terms of energy efficiency due to long working hours, intensive energy use, and high carbon emissions. In other words, hospitals have a significant share in energy consumption, so providing energy efficiency is quite essential for this industry. Therefore, energy performance management of these buildings is important to achieve sustainability goals.

Literature is evaluated in the second part. Methodology is detailed in the following section. The fourth part consists of the results of the proposed model. The final sections explain the discussion and conclusions.

2. Literature review

In this section, the results of the literature review are indicated based on each significant indicator of the energy performance management system. The summary of these studies is given in table A1. Many scholars in literature define that energy efficiency is an important indicator of the effective energy performance management system. Because of the environmental impacts and financial consequences of energy use, energy efficiency is an especially critical issue in the construction and operation of buildings and institutions (Sun *et al* 2022). Energy savings are achieved through reduced environmental consequences because of improved building energy efficiency (Siddik *et al* 2023). As a result, energy consumption and associated costs can be reduced by using energy-efficient devices (Chiu *et al* 2022). From a financial standpoint, this is a huge advantage. Therefore, the use of energy-saving technology in the G7 countries contributes to the adoption of an ecologically responsible approach by reducing the energy use of buildings and hospitals (Kanchiralla *et al* 2020). Popescu *et al* drew attention to the importance of system quality to increase energy efficiency in hospitals. Hospital HVAC and lighting systems were analyzed for this research to see how they are stacked up against each other in terms of energy efficiency and environmental friendliness (Zhang *et al* 2022). The research revealed that systems need to be redesigned, improved, and maintained to improve energy efficiency. Bampatsou and Halkos (2019) emphasized the importance of using smart building technologies to improve the quality of energy use in buildings. In this study, it is examined how smart building technologies can be used to increase the energy efficiency of buildings, reduce carbon footprint, and increase human comfort.

Moreover, the importance of technological improvement for energy performance management system is also highlighted in different studies. It is particularly important to have a high-quality system for efficient energy use (Jung and Jazizadeh 2019, Yasin *et al* 2023). System quality refers to a collection of energy-saving technologies installed in commercial and medical structures (Fichera *et al* 2020, Doğan *et al* 2022). These innovations are to reduce the environmental impact of buildings and hospitals and their energy use (Su *et al* 2022). Sharpe *et al* (2019) analyzed different strategies and policies that can be implemented in hospitals to increase energy efficiency. As a result of this article, they have shown that it is possible to reduce the energy consumption of hospitals by using the system dynamics model. Soni *et al* (2022) they examined the effect of increasing energy efficiency using solar energy in a hospital in Germany. The results of the study showed that the use of solar energy reduces energy consumption and provides hospital managers with significant savings.

Effective regulations play a critical role to improve energy performance management systems. Increasing energy demand, global climate change, and limited energy resources have made it necessary to regulate energy use. Building and healthcare facility energy consumption rules are becoming more important in this setting. About 40% of the total energy used in the G7 nations is used to power buildings (Dadi *et al* 2022). As a result, it presents a significant chance to cut down on carbon dioxide emissions by decreasing the amount of energy needed to power buildings (Chang and Hu 2019). To that end, codes have been drafted to mandate greater building efficiency when it comes to energy use (Batlle *et al* 2020). Energy labeling and building energy performance requirements are two areas where the European Union has adopted legislation (Eti *et al* 2023a). By mandating greater energy efficiency in buildings, the government hopes to cut down on energy use and greenhouse gas emissions (Lagrange *et al* 2020, Nundy *et al* 2021, Kou *et al* 2022, Xu *et al* 2022). Therefore, comparing the energy consumption of these areas to the market is crucial. This comparison creates a competitive environment among similar structures in terms of energy efficiency (Ding and Liu 2020). Among similar structures, those that are more efficient and consume less energy come to the fore and become more attractive. This, in turn, acts as an incentive mechanism to increase energy efficiency (Arjunan *et al* 2020). Comparing with the market is also important for measuring the level of energy efficiency. A building's or hospital's energy efficiency may be better understood when compared to that of other comparable buildings. The factors that affect a building's or hospital's energy usage may then be isolated, and from there, actions to increase efficiency can be devised (Kim *et al* 2019). Hashempour *et al* (2020) analyze how different strategies for energy conservation can affect hospital energy use in their article. Therefore, it shows that hospitals can save energy while also saving money by implementing appropriate energy efficiency measures. Schibuola and Tambani (2021) examined how important energy efficiency investments are in the commercial real estate sector. The bottom line is that energy efficiency investments can reduce the operating costs of buildings, increase tenant satisfaction, and increase building value.

Increasing energy demand should also be taken into consideration for the development of the energy performance management system. G7 countries consist of the most developed and economically powerful countries in the world. However, the demand for and use of energy in these nations is growing at an alarming rate (Yüksel *et al* 2022, Yan *et al* 2023). Population expansion, new manufacturing techniques, technical progress, and increased building energy use are all contributing elements (Ahmadi and Frikha 2022). For this reason, the G7 nations place a premium on the measurement and control of energy usage in buildings and hospitals to guarantee both energy efficiency and sustainability (Yang *et al* 2022). There are several advantages to assessing and controlling healthcare facilities' energy use. To begin with, lowering energy usage may lessen the financial burden on building and healthcare operations (Sohail *et al* 2023). In addition, cutting down on energy use may help create a more sustainable future by lessening the strain on the environment (Andersson *et al* 2021). The comfort of buildings and the contentment of hospital patients and visitors both rise when energy efficiency is improved (Sovacool *et al* 2022). Sahu *et al* (2022) and Coletta *et al* (2021) focus on the importance of increasing energy efficiency in buildings in their articles.

As a result of the literature review, it is possible to reach the following conclusions. Energy performance management is a very important issue in terms of sustainability. Moreover, energy management in hospitals has become very popular in the literature in recent years. There are many variables that have an important role on the effectiveness of energy performance management of buildings, such as energy efficiency, quality of the system and regulatory requirements. However, these improvements also lead to an increase in the costs of the enterprises. But hospitals and buildings are unlikely to improve each of these factors at the same time. Therefore, among these actions, the more important ones need to be determined. In this way, businesses will be able to use their limited budgets for more priority issues. Nevertheless, there are limited studies in literature that focused on the details of these issues. Hence, for satisfying this missing part, in this study, it is aimed to make a priority analysis for the indicators of energy performance management system with a novel methodology. On the other side, decision-making methodologies were also taken into consideration in some of these studies. However,

Table 1. Linguistic variable for weighting.

	μ	v	π
1 (Absolutely low importance -ALI)	,1	,9	,1
2 (Very low importance-VLI)	,2	,8	,2
3(Low importance-LI)	,3	,7	,3
4 (Slightly low importance-SLI)	,4	,6	,4
5 (Equally importance-EI)	,5	,5	,5
6 (Slightly more importance-SMI)	,6	,4	,4
7 (High importance-HI)	,7	,3	,3
8 (Very high importance-VHI)	,8	,2	,2
9 (Absolutely more importance-AMI)	,9	,1	,1

these existing models are criticized by many researchers. One of the most significant criticisms is related to the ranking techniques. In this context, TOPSIS approach includes Euclidian distance in the calculation process. Nonetheless, some scholars criticized this situation while calculating the distance to the negative ideal result. By considering these factors, it is understood that a new ranking model should be generated to overcome these problems. For this purpose, RATGOS technique is proposed in this study newly by the authors. In the calculation steps of this approach, geometrical mean is taken into consideration.

3. Methodology

This section consists of the operational steps of the decision-making techniques used in the proposed model.

3.1. Spherical Fuzzy CRITIC

The CRITIC method is used as a weighting method in solving decision making problems. The method in question calculates the weight of the criteria, taking into consideration the correlation between the criteria (Amin *et al* 2022, Krishankumar *et al* 2022). The steps of this method are given below (Haktanır and Kahraman 2022).

Step 1: Expert opinions are obtained and converted into fuzzy numbers with the help of the expressions in table 1. In this context, μ, v, and π membership, non-membership, and hesitancy degrees (Liu *et al* 2022).

Step 2: The arithmetic average (SWAM) of the obtained expert opinions is taken and the decision matrix (D) is created. In this process, equations (1) and (2) are used.

$$SWAM(D_{s1},\ D_{s2},\ldots,D_{Sn})=\left\{\begin{array}{c}\left[1-\prod_{i=1}^{n}(1-\mu_{D_{si}}^{2})^{\frac{1}{n}}\right]^{\frac{1}{2}},\\ \prod_{i=1}^{n}v_{D_{si}}^{\frac{1}{n}},\\ \left[\prod_{i=1}^{n}(1-\mu_{D_{si}}^{2})^{1/n}-\prod_{i=1}^{n}(1-\mu_{D_{si}}^{2}-\pi_{D_{si}}^{2})^{1/n}\right]^{1/2}\end{array}\right\} \tag{1}$$

$$D=\begin{bmatrix}(\mu_{11},\ v_{11}\pi_{11}) & \cdots & (\mu_{m1},\ v_{m1},\ \pi_{m1})\\ \vdots & \ddots & \vdots\\ (\mu_{1n},\ v_{1n},\pi_{1n}) & \cdots & (\mu_{mn},\ v_{mn},\pi_{1mn})\end{bmatrix} \tag{2}$$

Step 3: Using equations (3) and (4), the decision matrix is normalized, and the normalized matrix (X) is obtained. In this framework, V denotes the maximum operator, $(\mu_{-},\ v_{-},\ \pi_{-})$ show minimum optimal value and $(\mu_{+},\ v_{+},\ \pi_{+})$ indicate maximum optimal value.

$$\tilde{x}_{ij}=\frac{1-\dfrac{\mu_{ij}^{2}X\mu_{-}^{2}+v_{ij}^{2}Xv_{-}^{2}+\pi_{ij}^{2}X\pi_{-}^{2}}{\mu_{ij}^{2}V\mu_{-}^{2}+v_{ij}^{2}Vv_{-}^{2}+\pi_{ij}^{2}V\pi_{-}^{2}}}{1-\dfrac{\mu_{-}^{2}X\mu_{+}^{2}+v_{-}^{2}Xv_{+}^{2}+\pi_{-}^{2}X\pi_{+}^{2}}{\mu_{-}^{2}V\mu_{+}^{2}+v_{-}^{2}Vv_{+}^{2}+\pi_{-}^{2}V\pi_{+}^{2}}}\quad \text{for positive attributes} \tag{3}$$

Table 2. Linguistic variables for ranking.

	a	b	c
1	0	0	,1
2	0	,1	,2
3	,1	,2	,3
4	,3	,4	,5
5	,3	,5	,7
6	,5	,6	,7
7	,7	,8	,9
8	,8	,9	1
9	,9	1	1

$$\tilde{x}_{ij} = \frac{1 - \dfrac{\mu_{ij}^2 X\mu_+^2 + v_{ij}^2 X v_+^2 + \pi_{ij}^2 X\pi_+^2}{\mu_{ij}^2 V\mu_+^2 + v_{ij}^2 V v_+^2 + \pi_{ij}^2 V\pi_+^2}}{1 - \dfrac{\mu_-^2 X\mu_+^2 + v_-^2 X v_+^2 + \pi_-^2 X\pi_+^2}{\mu_-^2 V\mu_+^2 + v_-^2 V v_+^2 + \pi_-^2 V\pi_+^2}} \quad \text{for negative attributes} \tag{4}$$

Step 4: With the help of equation (5), the correlation coefficient is calculated over the normalized matrix.

$$\tilde{\rho}_{jk} = \sum_{i=1}^{m} (\tilde{x}_{ij} - \tilde{\bar{x}}_j)(\tilde{x}_{ik} - \tilde{\bar{x}}_k) \Big/ \sqrt{\sum_{i=1}^{m} (\tilde{x}_{ij} - \tilde{\bar{x}}_j)^2 \sum_{i=1}^{m} (\tilde{x}_{ik} - \tilde{\bar{x}}_k)^2} \tag{5}$$

In this process, $\tilde{\bar{x}}_j$ and $\tilde{\bar{x}}_k$ values are the fuzzy average values of j and k criteria. This value is also calculated by equation (6).

$$\tilde{\bar{x}}_j = \frac{1}{n} \sum_{j=1}^{n} \tilde{x}_{ij} \quad i = 1, 2, \ldots, m \tag{6}$$

Step 5: The standard deviation ($\tilde{\sigma}$) is computed by equation (7).

$$\tilde{\sigma}_j = \sqrt{\frac{1}{n-1} \sum_{j=1}^{n} (\tilde{x}_{ij} - \tilde{\bar{x}}_j)^2} \quad i = 1, 2, \ldots, m \tag{7}$$

Step 6: The index (C) value is calculated using equation (8).

$$\tilde{C}_j = \tilde{\sigma}_j \sum_{k=1}^{n} (1 - \tilde{\rho}_{jk}) \quad j = 1, 2, \ldots, n \tag{8}$$

Step 7: The weight (w) of each criterion is calculated by equation (9).

$$\tilde{w}_j = \frac{\tilde{C}_j}{\sum_{j=1}^{n} \tilde{C}_j} \tag{9}$$

3.2. Fuzzy RATGOS

In this study, a new decision-making technique is proposed with the name of Ranking Technique by Geometric Mean of Similarity Ratio to Optimal Solution (RATGOS). Similar approaches in literature have been criticized in many ways. In this framework, the Euclidian distance is used in the analyzes made with the TOPSIS technique (Krishankumar and Ecer 2023). On the other hand, the distance to both positive and negative ideal results is considered in the TOPSIS method (Alshamrani *et al* 2023). In this process, it is claimed that it is not correct to use the Euclidian distance to calculate the negative ideal result (Deng and Chen 2022). When these issues are taken into consideration, it is seen that a new technique needs to be developed (Majumder *et al* 2023). To achieve this aim, the RATGOS method, in which the geometric mean is used, is recommended. In this study, the RATGOS method is considered together with fuzzy numbers. The details of the calculation steps of the method are given below.

Step 1: Expert opinions are taken and converted into fuzzy numbers using the linguistic expressions in table 2.

Step 2: The decision matrix ($\tilde{S}$) is formed by averaging the triangular evaluations obtained with the help of equations (10) and (11).

$$\tilde{S} = \begin{bmatrix} \tilde{s}_{11} & \cdots & \tilde{s}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{s}_{m1} & \cdots & \tilde{s}_{mn} \end{bmatrix} \tag{10}$$

$$\tilde{s}_{ij} = \frac{\tilde{s}_{ij}^{1} + \tilde{s}_{ij}^{2} + \ldots + \tilde{s}_{ij}^{k}}{k} \tag{11}$$

Step 3: The optimal value is determined for each criterion. In this process, equations (12) and (13) are used for benefit and cost criteria.

$$\tilde{optimal} = \max \tilde{s}_j \tag{12}$$

$$\tilde{optimal} = \max 1/\tilde{s}_j \tag{13}$$

Step 4: Each criterion is divided by the optimal value. Thus, both normalization $(\tilde{A})$ is performed and the similarity ratio with respect to the optimal is calculated. In this process, equations (14)–(16) is taken into consideration.

$$\tilde{A} = \frac{\tilde{S}}{\tilde{optimal}} \quad for\ benefit \tag{14}$$

$$\tilde{A} = \frac{\tilde{optimal}}{\tilde{S}} \quad for\ cost \tag{15}$$

$$(a_1, b_1, c_1) \div (a_2, b_2, c_2) = \left(\frac{a_1}{c_2}, \frac{b_1}{b_2}, \frac{c_1}{a_2}\right) \tag{16}$$

Step 5: These values are multiplied by the weights (w) to obtain the weighted normalization matrix $(\tilde{T})$ by equations (17) and (18).

$$\tilde{T} = \begin{bmatrix} x_{11}, y_{11}, z_{11} & \cdots & x_{1n}, y_{1n}, z_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1}, y_{m1}, z_{m1} & \cdots & x_{mn}, y_{mn}, z_{mn} \end{bmatrix} = w^{*}\tilde{A} \tag{17}$$

$$\lambda^{*}(a, b, c) = (\lambda a, \lambda b, \lambda c) \tag{18}$$

Step 6: With the help of equation (19), the geometric mean $(\tilde{G})$ of the weighted normalized matrix is taken.

$$\tilde{G_j} = (g_{1j}, g_{2j}, g_{3j}) = \left(\sqrt[n]{\prod_{i=1}^{n} x_{ij}}, \sqrt[n]{\prod_{i=1}^{n} y_{ij}}, \sqrt[n]{\prod_{i=1}^{n} z_{ij}}\right) \tag{19}$$

Step 7: The calculated $(\tilde{G_j})$ values are defuzzified by equation (20) and alternatives can be ranked.

$$G_j = \frac{g_{1j} + g_{2j} + g_{3j}}{3} \tag{20}$$

4. Analysis results

The following subtitles give information about the results of the proposed model.

4.1. Identification of the criteria/alternatives and obtaining the expert evaluations

The ISO 50006 standard provides methods and guidelines for performance measurements of energy management systems and is used to improve the effectiveness of energy performance management of buildings in hospitals and the service industry (Andersson *et al* 2021). ISO 50006 is a standard for measurement and evaluation from the boundaries of energy management (Batlle *et al* 2020). This standard provides a framework for energy management consumption design, consumption, and savings (Fichera *et al* 2020). In this study, based on the results of the literature examination, 5 indicators are selected based on ISO 50006 standards. These factors are explained in table 3.

Energy efficiency refers to how effectively a system or process can use energy to achieve desired results with a given energy input. Basically, energy efficiency is the ability to do the same job with less energy consumption. Ensuring energy efficiency is very important in many ways. Energy production is often associated with the production of environmentally harmful gases, greenhouse gases and waste. Energy efficiency reduces environmental impacts by reducing energy demand. Less energy consumption contributes to the reduction of greenhouse gas emissions and the conservation of natural resources. Energy efficiency is important for a sustainable energy future by enabling more efficient use of energy resources. In a world where energy demand is

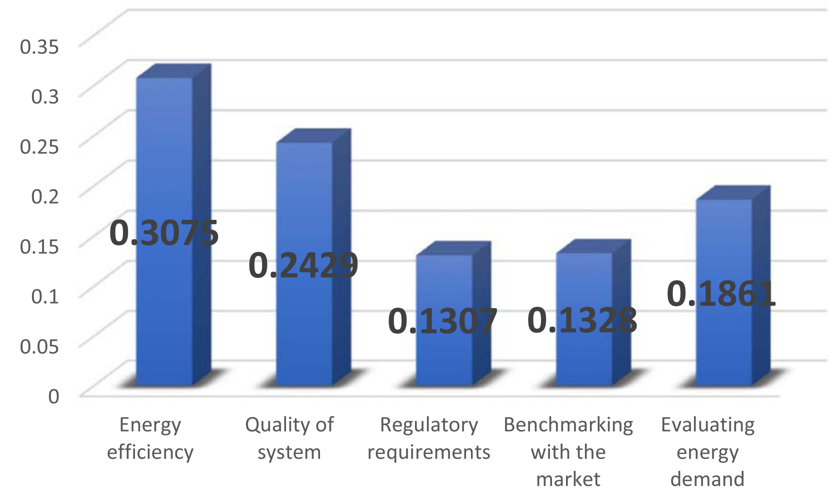

Figure 1. Weights of the indicators.

Table 3. Indicators.

Indicators	Supported literature
Energy efficiency	Dong *et al* (2022), Gan *et al* (2022)
Quality of system	Chen *et al* (2022), Dinçer *et al* (2023)
Regulatory requirements	Wang *et al* (2022), Akram *et al* (2022)
Benchmarking with the market	Hakimi *et al* (2023), Eti *et al* (2023b)
Evaluating energy demand	Ferrari *et al* (2023), Su *et al* (2022)

Table 4. Index values (C) and criteria weights (W).

	C	W
Energy efficiency	,1755	,3075
Quality of system	,1387	,2429
Regulatory requirements	,0746	,1307
Benchmarking with the market	,0758	,1328
Evaluating energy demand	,1062	,1861

constantly increasing, energy efficiency ensures a longer and more sustainable use of energy resources. The evaluations of these three people are detailed in table A2.

4.2. Computing the weights of the indicators

Expert opinions are converted into fuzzy numbers using the values in table 1. On the other hand, the decision matrix (D) is created with the help of equation (1). The details of this matrix are shown in table A3. Since all criteria are benefit, D matrix is normalized using equation (3) (table A4). Correlation coefficients are calculated with the help of equation (5) and shown in table A5. The standard deviation value of each criterion is calculated with the help of equation (7). Table A6 gives information about these values. In the last step, the importance weights of the criteria are calculated using equations (8) and (9). The results are presented in table 4.

Also, the weights of the criteria are illustrated in figure 1.

4.3. Ranking G7 countries

First, the expert opinions are converted into triangular fuzzy numbers. Then, with the help of equations (10) and (11), the decision matrix for the ranking is created. The triangular decision matrix is presented in table A7. Since the criteria are benefit, optimal values are calculated with the help of equation (12) and normalized with equation (14) (table A8). By using the weights obtained with Spherical fuzzy Critic and equation (17), a weighted normalized matrix was obtained. The resulting matrix is shown in table A9. G matrix is obtained by

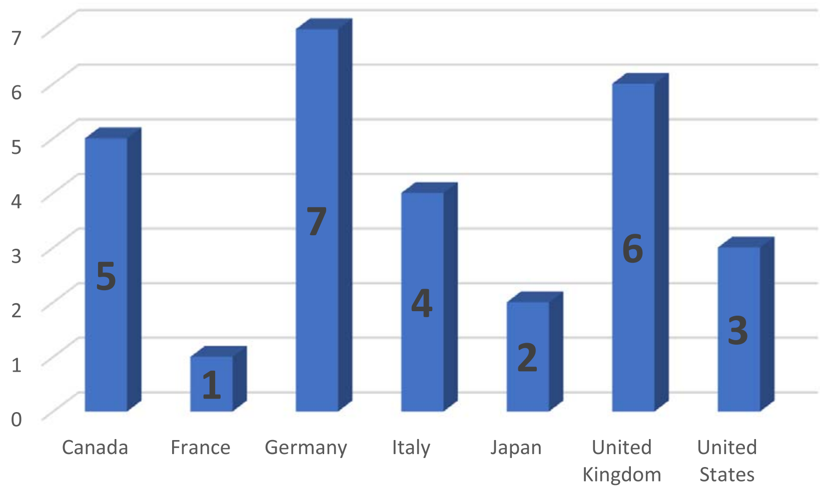

Figure 2. Ranking results of G7 economies.

Table 5. Defuzzified values and ranking results.

	Defuzzied values	Ranking results
Canada	,0668	5
France	,1899	1
Germany	,0618	7
Italy	,0693	4
Japan	,1786	2
United Kingdom	,0657	6
United States	,0927	3

equation (19) and presented in table A10. Finally, the values in G matrix are defuzzified by using equation (20). The highest defuzzifed value gives information about the best alternative. The findings are indicated in table 5.

Figure 2 also explains the ranking results of G7 economies.

It is identified that France is the most successful G7 economy with respect to the energy performance management. Japan and United States have also high performance in this respect. On the other side, United Kingdom and Germany are on the last ranks in this framework.

5. Discussion

According to the results obtained in this study, the most important issue affecting the energy performance management process in hospitals was found to be ensuring energy efficiency. It is known that energy consumption is high in hospitals. Apart from this, energy is one of the largest components that make up the expenses of both hospitals and other buildings. In addition, energy prices can easily fluctuate as they are affected by economic crises and global events. Therefore, ensuring energy efficiency is very important for buildings. Accordingly, energy efficiency should be provided for hospitals to successfully realize energy performance management. To achieve this goal, hospitals need a good technological infrastructure. In addition, having qualified personnel who can use this advanced technology is another important factor that can affect the process. Except for this, measuring the amount of energy required by the hospital and acting accordingly will impress energy performance. Additionally, energy efficiency can be improved by comparing the practices of buildings and countries that are successful in energy performance management and energy efficiency.

Ensuring energy efficiency in buildings is also a very important issue. Buildings often account for a large portion of energy consumption. Energy efficiency measures reduce energy consumption in buildings and thus save energy. A well-insulated building reduces heating and cooling costs by making more efficient use of energy resources. Energy efficient buildings save on operating and usage costs, along with lower energy bills. Well-insulated buildings consume less energy and therefore reduce energy costs. In addition, the long-term economic return of energy-efficient technologies and systems can be high. On the other hand, energy efficient buildings comply with sustainability goals and create a green image. This is important for buildings' participation in certification programs and compliance with sustainable building standards. Energy efficient buildings encourage the spread of green construction practices and innovative solutions (Candila *et al* 2021, Saqib *et al* 2021, An *et al* 2020).

Many studies in the literature have emphasized that achieving energy efficiency plays an important role in energy performance management. Cai *et al* (2022) conducted a review of research examining energy performance improvement methods to ensure sustainable production. Accordingly, 166 articles were analyzed, and it was understood that ensuring energy efficiency has an important place in energy performance management. Santolamazza *et al* (2023) used a maturity model in their study on the energy performance management of companies in Italy. According to the study, which examined the reports of large companies in Italy, where it is obligatory to conduct energy audits every four years, companies that provide energy efficiency are more successful in the energy management process. Hasan and Trianni (2020) carry out a study examining the relationship between industrial energy efficiency and energy management processes. In the study, the importance of ensuring energy efficiency to reduce greenhouse gases and energy consumption was pointed up. Quiang *et al* (2023) managed a review study on energy management processes in green buildings. In the study, it is defined that buildings account for 40% of global energy consumption and that energy efficiency should be ensured. Castrillon-Mendoza *et al* 2020 investigated the relationship between climate change, carbon emissions, and energy consumption in industrialized countries with a case study. The importance of energy efficiency is also underlined in the study, which expresses the necessity of an environmentally friendly and cleaner production process. Apart from these, Flick *et al* (2020) and Manfren and Nastasi (2020) stated that calculating the amount of energy to be consumed in the energy performance management process also plays an important role.

According to another result obtained in our study, the quality of technological equipment used in service production has an important place in the measurement of energy performance. One of the biggest obstacles to the success of the energy performance management process is unnecessary and excessive energy consumption. Therefore, the establishment of a system that will prevent unnecessary and excessive energy consumption will contribute to the success of the energy performance management process. This will also contribute to reducing the costs of hospitals. Pappalardo and Reverdy (2020) ran a study covering technological infrastructure and energy performance management in buildings in France. According to the results of the study, the quality of the system has an important place in the energy performance management process. Hammad (2019) administered a study examining the reasons for the difference between predicted and actual energy consumption to increase efficiency in building energy performance. It is defined in the study results that the use of advanced technologies directly affects energy performance management. Al Hashmi *et al* made a study to reduce carbon emissions with multi-criteria decision-making techniques. According to the study conducted in Saudi Arabia, the increase in energy consumption should be prevented due to the increasing population. To achieve this goal, it is stated that technology should be utilized in addition to many other methods.

Energy performance management of buildings is especially important for developing countries. The population growth rate in developing countries is quite high. In addition, these countries are taking action to increase their economic growth. These issues cause the demand for energy to increase rapidly. Therefore, the high energy performance of buildings will contribute to the reduction of energy consumption in developing countries. Thus, a radical increase in energy demand will be prevented. Consequently, extraordinary increases in energy demand can be mitigated by managing the energy performance of buildings. So, energy performance management is more important for developing countries than for other countries. In this context, developing countries are analyzed in this study. According to the results of the analysis, the most successful country was China. This shows that China has taken more accurate steps to manage the energy performance of its buildings. Hence, it will also increase the economic performance of successful countries. These countries will be able to manage their energy demands and avoid extra costs. Then, developing countries that aim to grow economically but are less successful in the energy performance management process can achieve their goals by implementing the strategies outlined in this study. Sharma *et al* investigated the relationship between renewable energy and the ecological footprint of eight developing countries in Asia. In the study, which concluded that renewable energy reduces the ecological footprint, it was also stated that the energy consumption of developing countries is high. Shahbaz *et al* (2021) examined the impact of financial development on renewable energy demand in developing countries. Using data from 1994–2015 and including 34 countries, the study drew attention to the increase in energy demand in developing countries.

Fuzzy decision-making models were also taken into consideration in the literature regarding the subject of energy performance management systems. Zhao *et al* (2022) focused on the energy performance management in the microgrid systems. In this framework, they created a fuzzy decision-making model by integrating DEMATEL and TOPSIS techniques. Similarly, Fazeli *et al* (2022), Bilgili *et al* (2022) and Li *et al* (2022) also used TOPSIS methodology to measure energy performance for different country groups. However, TOPSIS methodology was also criticized by different scholars because of using the Euclidian distance to calculate the negative ideal result (Deng and Chen 2022, Corrente and Tasiou 2023). To overcome these criticisms, RATGOS technique is created by the authors in this study as a new ranking approach. On the other side, Jangre *et al* (2022), Tippu *et al* (2022) and Feng *et al* (2022) considered DEMATEL technique to weight the main indicators of energy performance management. However, the scholars criticized DEMATEL especially when there are symmetrical evaluations. In this process, it is claimed that the DEMATEL technique incorrectly calculates the importance weights of the criteria as equal (Özdemirci *et al* 2023). For handling these problems, CRITIC methodology is taken into consideration in this proposed model.

6. Conclusions

Main indicators of energy performance management system are evaluated. Within this framework, a novel model is generated to make a priority analysis. In the first stage, five indicators of energy performance management system are identified based on ISO 50006 standards. Additionally, these indicators are examined by using Spherical fuzzy CRITIC. In the second part of the proposed model, G7 countries are ranked with fuzzy RATGOS technique. It is concluded that energy efficiency is the most crucial indicator of energy performance management. Additionally, the quality of the system should also be taken into consideration in this context. However, the weights of the regulatory requirements and benchmarking are much lower than other factors. On the other side, based on the ranking results, it is identified that France is the most successful G7 economy with respect to the energy performance management. Japan and United States have also high performance in this respect. Nonetheless, United Kingdom and Germany are on the last ranks in this framework.

Identification of the most significant indicators of the energy performance systems is an important novelty of this study. With the help of this issue, companies can use their limited budgets for more priority issues. The most significant methodological novelty of this study is proposing a new technique to the literature named RATGOS. Existing similar techniques in literature are criticized because of some issues. Because of this issue, the RATGOS method, in which the geometric mean is used, is recommended. The main limitation of this study is that it focused only on hospitals in the analysis process. The issue of energy performance management is also important for other sectors. Therefore, future studies in other sectors such as textile and automotive can be considered in this context. On the other hand, G7 countries are taken into account in the analysis process of this study. On the other hand, the success of energy performance management is also very important for developing countries. In this context, these countries can be analyzed in a new study to be conducted.

Acknowledgments

Alexey Mikhaylov performed the work in Sections 3–6, which were funded by Russian Science Foundation (Agreement 23-41-10001), https://rscf.ru/project/23-41-10001/ Gabor Pinter performed the work in Sections 1–2, which been implemented Project no. RRF-2.3.1-21-2022-00009, titled National Laboratory for Renewable Energy has been implemented with the support provided by the Recovery and Resilience Facility of the European Union within the framework of Programme Széchenyi Plan Plus.

Data availability statement

The data cannot be made publicly available upon publication because no suitable repository exists for hosting data in this field of study. The data that support the findings of this study are available upon reasonable request from the authors.

Appendix

Table A1. Literature review summary.

Studies	Important results
(Sun et al 2022)	Energy efficiency is an important indicator of the effective energy performance management system.
(Siddik et al 2023)	
(Chiu et al 2022)	
(Kanchiralla et al 2020)	
(Zhang et al 2022)	
(Bampatsou and Halkos 2019)	
(Jung & Jazizadeh 2019)	Technological improvement has a critical importance for energy performance management system.
(Yasin et al 2023)	
(Fichera et al 2020)	
(Doğan et al 2022)	
(Su et al 2022)	
(Sharpe et al 2019)	
(Soni et al 2022)	
(Dadi et al 2022)	Effective regulations play a significant role to improve energy performance management systems.
(Chang and Hu 2019)	
(Batlle et al 2020)	
(Eti et al 2023a)	
(Xu et al 2022)	
(Nundy et al 2021)	
(Lagrange et al 2020)	
(Kou et al 2022)	
(Ding and Liu 2020)	
(Arjunan et al 2020)	
(Kim et al 2019)	
(Hashempour et al 2020)	
(Schibuola and Tambani 2021)	
(Yüksel et al 2022)	Increasing energy demand should also be taken into consideration for the development of the energy performance management system.
(Yan et al 2023)	
(Ahmadi and Frikha 2022)	
(Yang et al 2022)	
(Sohail et al 2023)	
(Andersson et al 2021)	
(Sovacool et al 2022)	
(Sahu et al 2022)	
(Coletta et al 2021)	

Table A2. Evaluations.

Expert 1					
	Energy efficiency	Quality of system	Regulatory requirements	Benchmarking with the market	Evaluating energy demand
Canada	9	3	4	4	3
France	9	7	9	7	8
Germany	8	3	4	4	3
Italy	5	3	4	3	4
Japan	9	8	9	7	8
United Kingdom	4	5	3	5	4
United States	4	4	3	4	5
Expert 2					
	Energy efficiency	Quality of system	Regulatory requirements	Benchmarking with the market	Evaluating energy demand
Canada	3	3	3	5	3
France	9	7	8	7	9
Germany	3	4	3	1	4
Italy	4	5	2	3	5
Japan	8	7	6	7	8
United Kingdom	3	3	5	4	3
United States	4	5	3	5	4
Expert 3					
	Energy efficiency	Quality of system	Regulatory requirements	Benchmarking with the market	Evaluating energy demand
Canada	4	4	3	2	3
France	8	7	6	8	9
Germany	3	2	4	3	2
Italy	4	5	3	2	4
Japan	6	7	6	8	7
United Kingdom	2	3	4	3	2
United States	5	4	6	5	4

Table A3. D matrix.

	Energy efficiency			Quality of system			Regulatory requirements			Benchmarking with the market			Evaluating energy demand		
	μ	ν	π	μ	ν	π	μ	ν	π	μ	ν	π	μ	ν	π
Canada	,69	,35	,12	,34	,66	,30	,34	,66	,40	,39	,62	,40	,30	,70	,30
France	,87	,13	,10	,70	,30	,30	,80	,20	,11	,74	,26	,30	,87	,13	,21
Germany	,58	,46	,21	,31	,70	,30	,37	,63	,40	,30	,72	,40	,31	,70	,30
Italy	,44	,56	,50	,45	,56	,30	,31	,70	,40	,27	,73	,30	,44	,56	,40
Japan	,80	,20	,11	,74	,26	,20	,76	,25	,11	,74	,26	,30	,77	,23	,20
United Kingdom	,31	,70	,40	,38	,63	,50	,41	,59	,30	,41	,59	,50	,31	,70	,40
United States	,44	,56	,40	,44	,56	,40	,44	,58	,30	,47	,53	,40	,44	,56	,50

Table A4. Normalized matrix.

	Energy efficiency	Quality of system	Regulatory requirements	Benchmarking with the market	Evaluating energy demand
Energy efficiency	,4351	,9707	,9760	,8579	1,0000
Quality of system	,0000	,1410	,0000	,0000	,0000
Regulatory requirements	,6580	1,0000	,9407	,9741	,9911
Benchmarking with the market	,8828	,8017	1,0000	1,0000	,8613
Evaluating energy demand	,1718	,0000	,1342	,0000	,2467

Table A5. Correlation coefficients.

	Energy efficiency	Quality of system	Regulatory requirements	Benchmarking with the market	Evaluating energy demand
Energy efficiency	1,0000	,7901	,8988	,9179	,8429
Quality of system	,7901	1,0000	,9605	,9678	,9561
Regulatory requirements	,8988	,9605	1,0000	,9895	,9838
Benchmarking with the market	,9179	,9678	,9895	1,0000	,9616
Evaluating energy demand	,8429	,9561	,9838	,9616	1,0000

Table A6. Standard deviation values.

Standard deviation values	Energy efficiency	Quality of system	Regulatory requirements	Benchmarking with the market	Evaluating energy demand
σ	,3190	,4260	,4459	,4649	,4157

Table A7. Decision matrix.

	Energy efficiency			Quality of system			Regulatory requirements			Benchmarking with the market			Evaluating energy demand		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Canada	,43	,53	,60	,17	,27	,37	,17	,27	,37	,20	,33	,47	,10	,20	,30
France	,87	,97	1,00	,70	,80	,90	,73	,83	,90	,73	,83	,93	,87	,97	1,00
Germany	,33	,43	,53	,13	,23	,33	,23	,33	,43	,13	,20	,30	,13	,23	,33
Italy	,30	,43	,57	,23	,40	,57	,13	,23	,33	,07	,17	,27	,30	,43	,57
Japan	,73	,83	,90	,73	,83	,93	,63	,73	,80	,73	,83	,93	,77	,87	,97
United Kingdom	,13	,23	,33	,17	,30	,43	,23	,37	,50	,23	,37	,50	,13	,23	,33
United States	,30	,43	,57	,30	,43	,57	,23	,33	,43	,30	,47	,63	,30	,43	,57

Table A8. Normalized values.

	Energy efficiency			Quality of system			Regulatory requirements			Benchmarking with the market			Evaluating energy demand		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Canada	,43	,55	,69	,18	,32	,50	,19	,32	,50	,21	,40	,64	,10	,21	,35
France	,87	1,00	1,15	,75	,96	1,23	,81	1,00	1,23	,79	1,00	1,27	,87	1,00	1,15
Germany	,33	,45	,62	,14	,28	,45	,26	,40	,59	,14	,24	,41	,13	,24	,38
Italy	,30	,45	,65	,25	,48	,77	,15	,28	,45	,07	,20	,36	,30	,45	,65
Japan	,73	,86	1,04	,79	1,00	1,27	,70	,88	1,09	,79	1,00	1,27	,77	,90	1,12
United Kingdom	,13	,24	,38	,18	,36	,59	,26	,44	,68	,25	,44	,68	,13	,24	,38
United States	,30	,45	,65	,32	,52	,77	,26	,40	,59	,32	,56	,86	,30	,45	,65

Table A9. Weighted normalized matrix.

	Energy efficiency			Quality of system			Regulatory requirements			Benchmarking with the market			Evaluating energy demand		
	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z
Canada	,13	,17	,21	,04	,08	,12	,02	,04	,07	,03	,05	,08	,02	,04	,06
France	,27	,31	,35	,18	,23	,30	,11	,13	,16	,10	,13	,17	,16	,19	,21
Germany	,10	,14	,19	,03	,07	,11	,03	,05	,08	,02	,03	,05	,02	,04	,07
Italy	,09	,14	,20	,06	,12	,19	,02	,04	,06	,01	,03	,05	,06	,08	,12
Japan	,23	,27	,32	,19	,24	,31	,09	,12	,14	,10	,13	,17	,14	,17	,21
United Kingdom	,04	,07	,12	,04	,09	,14	,03	,06	,09	,03	,06	,09	,02	,04	,07
United States	,09	,14	,20	,08	,13	,19	,03	,05	,08	,04	,07	,11	,06	,08	,12

Table A10. G matrix.

	g1	g2	g3
Canada	,0375	,0646	,0983
France	,1541	,1875	,2280
Germany	,0355	,0588	,0911
Italy	,0356	,0665	,1057
Japan	,1426	,1750	,2181
United Kingdom	,0346	,0628	,0996
United States	,0566	,0892	,1324

ORCID iDs

Serkan Eti https://orcid.org/0000-0002-4791-4091
Yaşar Gökalp https://orcid.org/0000-0002-3390-4597
Alexey Mikhaylov https://orcid.org/0000-0003-2478-0307
Gabor Pinter https://orcid.org/0000-0002-3420-8390

References

Ahmadi Z and Frikha W 2022 Consumption-based carbon dioxide emissions and their impact on energy productivity in the G7 countries *Journal of the Knowledge Economy* 1–16
Akram R, Umar M, Xiaoli G and Chen F 2022 Dynamic linkages between energy efficiency, renewable energy along with economic growth and carbon emission. a case of mint countries an asymmetric analysis *Energy Reports* **8** 2119–30
Alshamrani A, Majumder P, Das A, Hezam I M and Božanić D 2023 An integrated BWM-TOPSIS-I approach to determine the ranking of alternatives and application of sustainability analysis of renewable energy *Axioms* **12** 159
Alwaelya S A, Yousif N B A and Mikhaylov A 2021 Emotional Development in Preschoolers and Socialization *Early Child Development and Care* **191** 16
Amin F U, Dong Q L, Grzybowska K, Ahmed Z and Yan B R 2022 A novel fuzzy-based VIKOR–CRITIC soft computing method for evaluation of sustainable supply chain risk management *Sustainability* **14** 2827
An J, Mikhaylov A and Jung S-U 2020 The Strategy of South Korea in the Global Oil Market *Energies* **13** 2491
Andersson E and Thollander P 2019 Key performance indicators for energy management in the Swedish pulp and paper industry *Energy Strategy Reviews* **24** 229–35
Andersson E, Dernegård H, Wallén M and Thollander P 2021 Decarbonization of industry: implementation of energy performance indicators for successful energy management practices in kraft pulp mills *Energy Reports* **7** 1808–17
Arjunan P, Poolla K and Miller C 2020 EnergyStar++: Towards more accurate and explanatory building energy benchmarking *Appl. Energy* **276** 115413
Bampatsou C and Halkos G 2019 Economic growth, efficiency and environmental elasticity for the G7 countries *Energy Policy* **13** 355–60
Batlle E A O, Palacio J C E, Lora E E S, Reyes A M M, Moreno M M and Morejón M B 2020 A methodology to estimate baseline energy use and quantify savings in electrical energy consumption in higher education institution buildings: case study, federal University of Itajubá (UNIFEI) *J. Clean. Prod.* **244** 118551
Bilgili F, Zarali F, Ilgün M F, Dumrul C and Dumrul Y 2022 The evaluation of renewable energy alternatives for sustainable development in Turkey using intuitionistic fuzzy-TOPSIS method *Renewable Energy* **189** 1443–58
Cai W, Wang L, Li L, Xie J, Jia S, Zhang X and Lai K H 2022 A review on methods of energy performance improvement towards sustainable manufacturing from perspectives of energy monitoring, evaluation, optimization and benchmarking *Renew. Sustain. Energy Rev.* **159** 112227
Chang M C and Hu J L 2019 A long-term meta-frontier analysis of energy and emission efficiencies between G7 and BRICS *Energ. Effic.* **12** 879–93
Castrillon-Mendoza R, Rey-Hernández J M and Rey-Martínez F J 2020 Industrial decarbonization by a new energy-baseline methodology *Case study. Sustainability* **12** 1960
Candila V, Maximov D, Mikhaylov A, Moiseev N, Senjyu T and Tryndina N 2021 On the Relationship between Oil and Exchange Rates of Oil-Exporting and Oil-Importing Countries: From the Great Recession Period to the COVID-19 Era *Energies* **14** 8046
Chen H, Shi Y and Zhao X 2022 Investment in renewable energy resources, sustainable financial inclusion and energy efficiency: a case of US economy *Resour. Policy* **77** 102680
Chiu C R, Chang M C and Hu J L 2022 Energy intensity improvement and energy productivity changes: an analysis of BRICS and G7 countries *Journal of Productivity Analysis* **57** 297–311
Coletta A M, Rose N B, Johnson A F, Moxon D S, Trapp S K, Walker D and Hansen P A 2021 The impact of a hospital-based exercise oncology program on cancer treatment–related side effects among rural cancer survivors *Supportive Care in Cancer* **29** 4663–72
Corrente S and Tasiou M 2023 A robust TOPSIS method for decision making problems with hierarchical and non-monotonic criteria *Expert Syst. Appl.* **214** 119045
Dadi D, Introna V, Santolamazza A, Salvio M, Martini C, Pastura T and Martini F 2022 Private hospital energy performance benchmarking using energy audit data: an Italian case study *Energies* **15** 806
Deng X and Chen C 2022 Novel linear programming models based on distance measure of IFSs and modified TOPSIS method for portfolio selection *Egyptian Informatics Journal* **23** 13–31
Dinçer H, Eti S, Gökalp Y, Yüksel S and Çelebi B 2023 . The role of small-scale wind turbines in increasing the competitiveness of hospitals *Handbook of Research on Quality and Competitiveness in the Healthcare Services Sector* (IGI Global) pp 336–52
Ding Y and Liu X 2020 A comparative analysis of data-driven methods in building energy benchmarking *Energy Build.* **209** 109711
Doğan B, Ghosh S, Hoang D P and Chu L K 2022 Are economic complexity and eco-innovation mutually exclusive to control energy demand and environmental quality in E7 and G7 countries? *Technology in Society* **68** 101867

Dong K, Dou Y and Jiang Q 2022 Income inequality, energy poverty, and energy efficiency: Who cause who and how? *Technol. Forecast. Soc. Change* **179** 121622
Eti S, Dinçer H, Gökalp Y, Yüksel S and Kararoğlu D 2023a Identifying key issues to handle the inflation problem in the healthcare industry caused by energy prices: an evaluation with decision-making models *Managing Inflation and Supply Chain Disruptions in the Global Economy* 162–78
Eti S, Dinçer H, Yüksel S and Gökalp Y 2023b Analysis of the suitability of the solar panels for hospitals: a new fuzzy decision-making model proposal with the T-Spherical TOP-DEMATEL method *Journal of Intelligent & Fuzzy Systems* (Preprint) 1–13
Fazeli A, Jalaei F, Khanzadi M and Banihashemi S 2022 BIM-integrated TOPSIS-Fuzzy framework to optimize selection of sustainable building components *International Journal of Construction Management* **22** 1240–59
Feng Z, Wu X, Chen H, Qin Y, Zhang L and Skibniewski M J 2022 An energy performance contracting parameter optimization method based on the response surface method: a case study of a metro in China *Energy* **248** 123612
Ferrari S, Zagarella F, Caputo P and Beccali M 2023 Mapping seasonal variability of buildings electricity demand profiles in mediterranean small islands *Energies* **16** 1568
Fichera A, Volpe R and Cutore E 2020 Energy performance measurement, monitoring and control for buildings of public organizations: standardized practises compliant with the ISO 50001 and ISO 50006 *Developments in the Built Environment* **4** 100024
Flick D, Keck C, Herrmann C and Thiede S 2020 Machine learning based analysis of factory energy load curves with focus on transition times for anomaly detection *Procedia CIRP* **93** 461–6
Gan X, Pei J, Pavesi G, Yuan S and Wang W 2022 Application of intelligent methods in energy efficiency enhancement of pump system: a review *Energy Reports* **8** 11592–606
Hakimi O, Liu H and Abudayyeh O 2023 Digital twin-enabled smart facility management: a bibliometric review *Frontiers of Engineering Management* 1–18
Haktanır E and Kahraman C 2022 A novel picture fuzzy CRITIC & REGIME methodology: wearable health technology application *Eng. Appl. Artif. Intell.* **113** 104942
Hammad A W 2019 Minimising the deviation between predicted and actual building performance via use of neural networks and BIM *Buildings* **9** 131
Hasan A M and Trianni A 2020 A review of energy management assessment models for industrial energy efficiency *Energies* **13** 5713
Hashempour N, Taherkhani R and Mahdikhani M 2020 Energy performance optimization of existing buildings: a literature review *Sustainable Cities and Society* **54** 101967
Jangre J, Prasad K, Kaliyan M, Kumar D and Patel D 2022 Sustainability assessment of waste cooking oil-based biodiesel plant in developing economy based on F-DEMATEL and F-ISM approaches *Waste Management & Research* **40** 1645–59
Jung W and Jazizadeh F 2019 Human-in-the-loop HVAC operations: a quantitative review on occupancy, comfort, and energy-efficiency dimensions *Appl. Energy* **239** 1471–508
Kanchiralla F M, Jalo N, Johnsson S, Thollander P and Andersson M 2020 Energy end-use categorization and performance indicators for energy management in the engineering industry *Energies* **13** 369
Kapp S, Choi J K and Kissock K 2022 Toward energy-efficient industrial thermal systems for regional manufacturing facilities *Energy Reports* **8** 1377–87
Karunanithi K, Ramesh S, Raja S P, Sreedhar R, Kannan S and Ramudu V 2023 Investigations of standalone PV system with battery-supercapacitor hybrid energy storage system for household applications *Int. J. Inf. Technol.* **15** 279–87
Kim D W, Kim Y M and Lee S E 2019 Development of an energy benchmarking database based on cost-effective energy performance indicators: Case study on public buildings in South Korea *Energy Build.* **191** 104–16
Kostis P, Dinçer H and Yüksel S 2022 Knowledge-based energy investments of European economies and policy recommendations for sustainable development *Journal of the Knowledge Economy* 1–33
Kou G, Yüksel S and Dinçer H 2022 Inventive problem-solving map of innovative carbon emission strategies for solar energy-based transportation investment projects *Appl. Energy* **311** 118680
Koutsandreas D, Kleanthis N, Flamos A, Karakosta C and Doukas H 2022 Risks and mitigation strategies in energy efficiency financing: a systematic literature review *Energy Reports* **8** 1789–802
Krishankumar R and Ecer F 2023 Selection of IoT service provider for sustainable transport using q-rung orthopair fuzzy CRADIS and unknown weights *Appl. Soft Comput.* **132** 109870
Krishankumar R, Pamucar D, Deveci M, Aggarwal M and Ravichandran K S 2022 Assessment of renewable energy sources for smart cities' demand satisfaction using multi-hesitant fuzzy linguistic based choquet integral approach *Renewable Energy* **189** 1428–42
Lagrange A, de Simón-Martín M, González-Martínez A, Bracco S and Rosales-Asensio E 2020 Sustainable microgrids with energy storage as a means to increase power resilience in critical facilities: an application to a hospital *Int. J. Electr. Power Energy Syst.* **119** 105865
Li J, Zhang R, Xu H and Feng J 2022 Two-stage design optimization of groove flow control technique to improve energy performance of an axial-flow pump *Journal of the Brazilian Society of Mechanical Sciences and Engineering* **44** 381
Liu P, Saha A, Mishra A R, Rani P, Dutta D and Baidya J 2022 A BCF–CRITIC–WASPAS method for green supplier selection with cross-entropy and Archimedean aggregation operators *Journal of Ambient Intelligence and Humanized Computing* 1–25
Majumder P, Paul A, Saha P, Majumder M, Baidya D and Saha D 2023 Trapezoidal fuzzy BWM-TOPSIS approach and application on water resources *Environment, Development and Sustainability* **25** 2648–69
Manfren M and Nastasi B 2020 Parametric performance analysis and energy model calibration workflow integration—A scalable approach for buildings *Energies* **13** 621
Manfren M, Tagliabue L C, Re Cecconi F and Ricci M 2022 Long-term techno-economic performance monitoring to promote built environment decarbonisation and digital transformation—a case study *Sustainability* **14** 644
Mutalimov V, Kovaleva I, Mikhaylov A and Stepanova D 2021 Assessing regional growth of small business in Russia *Entrepreneurial Business and Economics Review* **9** 119–133
Nundy S, Mesloub A, Alsolami B M and Ghosh A 2021 Electrically actuated visible and near-infrared regulating switchable smart window for energy positive building: a review *J. Clean. Prod.* **301** 126854
Özdemirci F, Yüksel S, Dinçer H and Eti S 2023 An assessment of alternative social banking systems using T-Spherical fuzzy TOP-DEMATEL approach *Decision Analytics Journal* 100184
Pappalardo M and Reverdy T 2020 Explaining the performance gap in a French energy efficient building: Persistent misalignment between building design, space occupancy and operation practices *Energy Research & Social Science* **7** 101809
Paramati S R, Shahzad U and Doğan B 2022 The role of environmental technology for energy demand and energy efficiency: evidence from OECD countries *Renew. Sustain. Energy Rev.* **153** 111735

Paris B, Vandorou F, Balafoutis A T, Vaiopoulos K, Kyriakarakos G, Manolakos D and Papadakis G 2022 Energy use in open-field agriculture in the EU: a critical review recommending energy efficiency measures and renewable energy sources adoption *Renew. Sustain. Energy Rev.* **158** 112098

Sahu P K, Solarin S A, Al-Mulali U and Ozturk I 2022 Investigating the asymmetry effects of crude oil price on renewable energy consumption in the United States *Environmental Science and Pollution Research* **29** 817–27

Santolamazza A, Introna V, Cesarotti V and Martini F 2023 The evolution of energy management maturity in organizations subject to mandatory energy audits: findings from Italy *Energies* **16** 3742

Saqib A, Chan T-H, Mikhaylov A and Lean H H 2021 Are the Responses of Sectoral Energy Imports Asymmetric to Exchange Rate Volatilities in Pakistan? Evidence From Recent Foreign Exchange Regime *Frontiers in Energy Research* **9** 614463

Schibuola L and Tambani C 2021 High energy efficiency ventilation to limit COVID-19 contagion in school environments *Energy Build.* **24** 110882

Shah W U H, Hao G, Yan H, Yasmeen R, Padda I U H and Ullah A 2022 The impact of trade, financial development and government integrity on energy efficiency: an analysis from G7-Countries *Energy* **255** 124507

Shahbaz M, Topcu B A, Sarıgül S S and Vo X V 2021 The effect of financial development on renewable energy demand: the case of developing countries *Renewable Energy* **178** 1370–80

Sharpe R A, Machray K E, Fleming L E, Taylor T, Henley W, Chenore T and Wheeler B W 2019 Household energy efficiency and health: area-level analysis of hospital admissions in England *Environ. Int.* **133** 105164

Siddik A B, Khan S, Khan U, Yong L and Murshed M 2023 The role of renewable energy finance in achieving low-carbon growth: contextual evidence from leading renewable energy-investing countries *Energy* **270** 126864

Sohail A, Du J and Abbasi B N 2023 Exploring the interrelationship among health status, CO2 emissions, and energy use in the top 20 highest emitting economies: based on the CS-DL and CS-ARDL approaches *Air Quality, Atmosphere & Health* 1–24

Soni N, Sharma D, Nimesh V and Reddy V M 2022 Solar energy assisted thermal treatment model to decontaminate airborne viruses in hospital *Thermal Science and Engineering Progress* **36** 101516

Sovacool B K, Upham P and Monyei C G 2022 The 'whole systems' energy sustainability of digitalization: humanizing the community risks and benefits of nordic datacenter development *Energy Research & Social Science* **88** 102493

Su B, Lin Y, Wang J, Quan X, Chang Z and Rui C 2022 Sewage treatment system for improving energy efficiency based on particle swarm optimization algorithm *Energy Reports* **8** 8701–8

Sun L, Peng J, Dinçer H and Yüksel S 2022 Coalition-oriented strategic selection of renewable energy system alternatives using q-ROF DEMATEL with golden cut *Energy* **256** 124606

Tippu J, Saravanasankar S, Sankaranarayanan B, Ali S M, Venkatesh V G, Qarnain S S and Sattanathan M 2022 Examining energy efficiency requirements in building energy standards: Implications of sustainable energy consumption *Energy Sources Part* B **17** 2084184

Wang Y, Deng X, Zhang H, Liu Y, Yue T and Liu G 2022 Energy endowment, environmental regulation, and energy efficiency: evidence from China *Technol. Forecast. Soc. Change* **177** 121528

Xu D, Sheraz M, Hassan A, Sinha A and Ullah S 2022 Financial development, renewable energy and CO2 emission in G7 countries: new evidence from non-linear and asymmetric analysis *Energy Econ.* **109** 105994

Yan C, Murshed M, Ozturk I, Siddik A B, Ghardallou W and Khudoykulov K 2023 Decarbonization blueprints for developing countries: The role of energy productivity, renewable energy, and financial development in environmental improvement *Resour. Policy* **83** 103674

Yang X, Li N, Mu H, Ahmad M and Meng X 2022 Population aging, renewable energy budgets and environmental sustainability: does health expenditures matter? *Gondwana Res.* **106** 303–14

Yasin I, Aslam A, Siddik A B, Abbass K and Murshed M 2023 Offshoring the scarring causes and effects of environmental challenges faced by the advanced world: an empirical evidence *Environmental Science and Pollution Research* 1–11

Yüksel S, Dinçer H, Mikhaylov A, Adalı Z and Eti S 2022 Key issues for the improvements of shallow geothermal investments *Sustainability in Energy Business and Finance: Approaches and Developments in the Energy Market* (Springer International Publishing) pp 183–94

Zakari A, Khan I, Tan D, Alvarado R and Dagar V 2022 Energy efficiency and sustainable development goals (SDGs) *Energy* **239** 122365

Zhang Y, Zhang Y, Gong C, Dinçer H and Yüksel S 2022 An integrated hesitant 2-tuple Pythagorean fuzzy analysis of QFD-based innovation cost and duration for renewable energy projects *Energy* **248** 123561

Zhao H, Li B, Lu H, Wang X, Li H, Guo S and Wang Y 2022 Economy-environment-energy performance evaluation of CCHP microgrid system: a hybrid multi-criteria decision-making method *Energy* **240** 122830