[*Analysis of Multi-Criteria Decision-Making Approaches for Industrial Energy Efficiency Projects Evaluation*]

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Overview

The energy sector has a considerable role in the economic system and in achieving United Nations (UN) sustainable development goals (Roth & Rajagopal, 2018), particularly goal number seven: "Affordable and clean energy." It is crucial to consider the energy transition towards renewable energy sources (e.g., solar, wind, and hydro) and improve the current infrastructure energy efficiency, which depends on non-renewable energy sources (e.g., coal and oil). A recent international energy agency (IEA) forecast predicts that in a sustainable development scenario, energy efficiency accounts for around 40% of total emission reductions by 2070 (IEA, 2020). In 2011, the United Nations Industrial Development Organization (UNIDO) collaborated with the International Organization for Standardization (ISO) to develop the energy management system (EnMS) ISO 50001; aiming to guide establishments to improve their energy performance, reduce energy use, and minimize environmental impact (McKane et al., 2017). Numerous countries now have a policy in place that supports the adaptation of the EnMS ISO 50001; according to an ISO survey, worldwide ISO 50001 certificates were issued to 18,227 organizations at 42,215 sites in 2019, compared to 7000 certifications in 2014.

One of the main requirements of EnMS implementation is the conduct of an energy review to identify opportunities for improvement of energy performance and prioritization of the identified energy efficiency projects (EEP) for implementation. Energy performance improvement opportunities can be evaluated and prioritized according to each organization's criteria (ISO, 2018). Examples of those criteria are energy-saving, economic (e.g., return on investment and capital cost), environmental impact (GHG reduction), technological risk, and non-energy benefits (e.g., maintenance enhancement and safety measures). Such a challenge points to the need for accessible methods that consider several relevant criteria, which decision-makers and technical experts can use in the prioritization process of EEP. A wide range of literature has used several methods, including Multi-Criteria Decision-Making (MCDM) to prioritize and rank energy projects (Mardani et al., 2015). Many MCDM studies focus on energy projects such as the evaluation of different energy sources, optimizing the energy mix, and prioritizing national energy policies. This study proposed the energy-efficiency projects evaluation framework using different MCDM methods. It is designed to consider balanced sustainability criteria and other non-energy benefits such as technological aspects. The result of the study shows the effectiveness of combining the FAHP approach with other MCDM techniques, i.e., utilizing FAHP method for calculating evaluation criteria weights and then using those weights to rank energy efficiency projects by VIKOR, TOPSIS, WSM, and PROMETHEE methods.

Methods

Despite the wide range of literature that has applied the combinations of FAHP with other MCDM techniques, no previous research has so far used them together to prioritize energy efficiency projects from the sustainability perspective. The proposed framework of this paper will be applied to a real case study of an industrial complex in Egypt to evaluate the EEP, as shown in Figure 1. Our framework consists of the following procedure:

I. Identify criteria for the evaluation of energy efficiency projects concerning sustainability dimensions.
II. Formation of the hierarchy structure and calculate the criteria wights using FAHP method.
III. Analyze the application of different MCDM methods (VIKOR, TOPSIS, WSM, WASPAS, and PROMETHEE) to the evaluation and prioritization of energy efficiency projects.

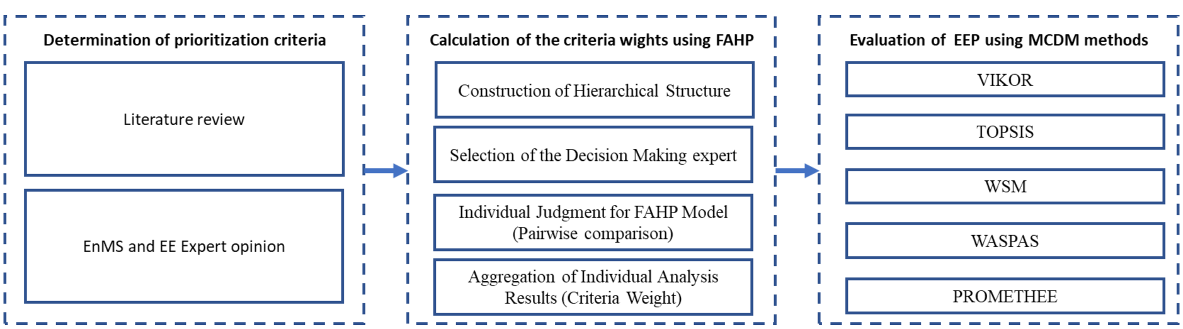

Figure 1 The framework structure of the proposed MCDM model

Results

The first step in the proposed framework is to identify the applicable criteria for evaluating EE projects; we obtained those criteria from a comprehensive literature review and validated the four main criteria and ten sub-criteria based on the opinions of 28 international EE experts. Then we applied the FAHP method to the calculation of criteria weights based on selected decision-making opinion as follows; implementation cost (0.146), energy cost-saving (0.259), project lifetime (0.046), emission reduction (0.0247), water-saving (0.058), regulatory requirement (0.049), impact on organizational reputation (0.02), technology availability (0.068), impact on maintenance and operation (0.054), implementation time (0.053). We also compared the result of the Egyptian firm with two firms from the EU and Gulf area to measure the organizational deference of the decision-making process regarding energy efficiency investment.

The second step is the prioritization of a list of EE projects identified during the energy audit process; the company technical team provides the numerical values of each EE project for each criterion. Five MCDM methods were utilized in the evaluation process to rank the proposed EE project list for implementation; the comparative results of the applied methodologies are shown in Table 1

Table 1 Comparative result of the MCDM methods for the evaluation of EE projects

Projects	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
VIKOR	12	2	5	8	1	7	10	3	11	6	9	4
TOPSIS	12	2	4	9	1	7	8	3	10	6	11	5
WSM	6	3	5	9	1	7	11	4	10	8	12	2
WASPAS	8	1	3	6	4	9	11	2	7	10	12	5
PROMETHEE	10	2	5	7	1	6	12	3	11	8	9	4

Conclusions

Improving energy efficiency in the current energy infrastructure and mainly energy-intensive industries is crucial for achieving sustainable development goals and avoiding the harmful impact of climate change. This study proposes a framework that combines FAHP to compute the evaluation criteria weights and various MCDM methods to evaluate and prioritize EE projects, considering sustainability dimensions as the evaluation criteria (economic, environmental, socio-political, and technological). The evaluation criteria and their weights might differ based on the organizational culture and national EE policies.

We have empirically applied our framework to an industrial complex in Egypt by achieving their objective of ranking the EE projects list as a crucial step of the EnMS ISO 50001 implementation procedures. The case example illustrates the effectiveness of the proposed model, which involves numerous evaluation criteria for energy efficiency projects. The results obtained by MCDM techniques indicate the consistency of VIKOR, TOPSIS, WSM, and PROMETHEE; while showing differences in the WASPAS method. Our study suggests that VIKOR, TOPSI, and WSM are preferable because of their consistency, simplicity, and the model's dynamics in evaluating EE projects.

The study introduces a practical framework for decision-makers and practitioners to improve their decision-making process related to sustainable energy efficiency investment. It can be applied in other case studies and provides a better understanding of the nature of the EE projects evaluation process.

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