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Subject review

Application of Multicriteria Decision Analysis Approach Managing Solar Prosumer Choices: Implications for Households, Regulatory Authorities, and Contractors

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Abstract: The research finds a rapidly growing solar energy industry with increasing dynamics, complexity, and heterogeneity of contingency variables affecting the rationale for solar investment decision-making. With a primary focus on the segment of individual households, the spectrum of possible solutions was evolving vastly. Consequently, the asymmetry of data access increases the risk exposure of the investment management decisions. In this context, applying a multicriteria decision analysis approach, the paper aims to support the decision-making process for individual households when evaluating and selecting solar PV installations. In this regard, the study found various techniques used by scholars, each with its applications and resulting differences. As a result, the interactive approach was chosen for qualitative judgements (using either qualitative or quantitative data) about differences in the utility of possible solar investment solutions to the individual household. The latter quantifies the relative attractiveness of solar PV installation offerings and contributes to the solar investment rationale. During the empirical investigation of Lithuanian households, 19 offerings, representing 83% of the market, were examined in three distinct scenarios. The study's results indicate that the offerings with the highest efficiency rates may not necessarily align with the optimal choices. Accordingly, the findings demonstrate the utility of the chosen approach extending beyond the solar prosumer's operational and tactical management tasks when assessing & selecting, deciding, commencing, and implementing the solution. It also reveals the impacts of changing metering schemes and fiscal and monetary regulations on investment performance and their effects on decision-making. Concerning regulatory authorities as if to improve support mechanisms for solar prosumers, the research revealed the potential to streamline the use of public funds. Respectively, for private organisations related to the solar industry, findings imply opportunities to improve supply chain operations and the timing of the execution of the contracts in connection to the content of the offerings.

Keywords: categorical based evaluation; economic utility; management; metering scheme; multiple criteria decisions; renewable energy

1 INTRODUCTION

Almost three decades already, power generation technologies have been put into focus and challenged continuously by regulatory frameworks across the globe. One of the main drivers of the regulatory impetus is the need to reduce emissions and combat climate change, transforming economies towards using technologies based on renewable energy sources (RES). The latest COP28 (Conference of the Parties) resulted in the declaration to transit away from fossil fuel (FF) based energy generation before 2050 while accelerating building renewable energy capacity to reach net-zero carbon emissions by 2050 [1]. In comparison to COP28 results, concerning the European Union (EU) context, the Renewable Energy Directive EU/2018/2001 was recently revised and entered into force on 20 November 2023 [2], setting already binding at least 42,5% (up from the previous set of 32%) target for 2030 of share of renewable energy with an ambition to reach 45%. Although fossil fuel-based solutions, such as those related to oil, coal, and natural gas, have long been the primary power generation energy sources. The dynamics in commodity prices over the last decade have indicated an imbalanced dependency on the latter [3]. To maintain competitiveness in the global market, organizations and economies must have mandatory power generation capacity. Yet, technologies subject to (FF) as to RES have limitations. Their combination to achieve secure and sustainable power generation requires rational matching, which can also be challenging due to the vast number of technologies available. Given the context, this paper is narrowed to photovoltaics (PV), a technology that converts light into electricity using semiconducting materials exhibiting the photovoltaic effect. The focus is on exploring the challenges prosumers (i.e. households that generate, store, and sell electricity) face when choosing solar PV installations. The significance of this study is also underscored by the lack of substantial scientific research concerning the application of multicriteria decision-making techniques for managing the objectives of selecting solar PV installations (from various solar PV manufacturers and their offerings) over the past decade. Despite an extensive review of scholarly works published across various Elsevier journals in recent years, only a few relevant researches on the latter subject could be identified. It was observed that scholars tend to focus on the solar PV plant site assessment for industries in various countries, as well as investigations of their economic utility and solving other tasks related to solar energy developments. In this respect the following multicriteria decision-making methods (MCDM) have been consistently used:

Analytic hierarchy process (AHP, i.e., Dsilva Winfred Rufuss et al. (2018) [4], Kocabaldır & Yücel (2023) [5]);

Complex proportional assessment (COPRAS; i.e., Alkan & Albayrak (2020) [6], Ao Xuan et al. (2022) [7]);

Data envelopment analysis (DEA; i.e., Dsilva Winfred Rufuss et al. (2018) [4], Wang et al. (2022) [8], Tajik et al. (2023) [9]);

Multi-objective optimisation by ratio analysis (MULTIMOORA, i.e., Alkan & Albayrak (2020) [6], Li et al. (2023) [10]);

Preference ranking organization method for enrichment evaluation (PROMETHEE i.e., Wu et al. (2019) [11], Ayough et al. (2022) [12]);

Simple additive weighting (SAW; i.e., Ayough et al. (2022) [12], Saracoglu (2020) [13]);

Compensatory aggregation method setting preference order based on similarity to ideal solution (TOPSIS, i.e., Hooshangi et al. (2023) [14], Kaur et al. (2023) [15];

ELimination et choix traduisant la REalité (ELimination Et Choice Translating REality (ELECTRE; i.e., Sánchez-Lozano et al. (2016) [16], Peng et al. (2019) [17], Thebault et al. (2022) [18]);

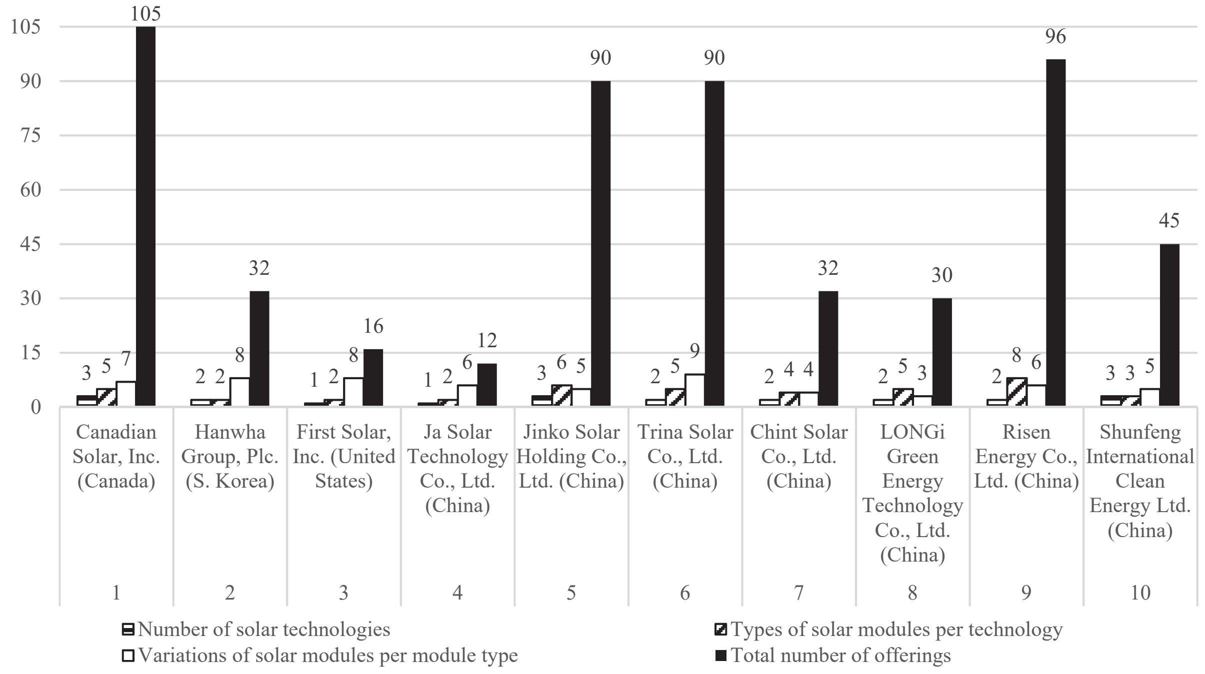
A solution for multicriteria optimisation & compromise (VIKOR (VIekriterijumsko KOmpromisno

Rangiranje); i.e., Shah et al. (2020) [19], Halil Yilmaz et al. (2023) [20]).

Furthermore, it was found that various MCDM methods are used together to ensure their reliability. This is because of differences in the algorithms, the criteria used, and the weightings assigned to each criterion. Consequently, selecting the appropriate one or combination of methods requires careful consideration of the advantages and disadvantages of each approach. The author will use the measuring attractiveness by a categorical based evaluation technique (MACBETH (Vieira et al. (2020) [21], Bana e Costa et al (2023) [22], T. Singh (2024) [23]) while experimenting with Lithuanian prosumers to address these gaps. The rationale behind selecting MACBETH as a method for deciding on solar PV panels is primarily because it can quantify the qualitative judgments, which is critical when precise and clear data needed for decision-making is not necessarily available to the needed extent. The article is divided into sections. The second reviews the literature on solar PV panels. The third focuses on the peculiarities and limitations of MCDM methods. Part 4 reveals the MACBETH application, followed by an analysis of the results when deciding on the right choice of solar PV installations. Part 5 discusses the outcomes of using MACBETH concerning the rationale of households' solar PV investment choices and respective government authorities to improve the management of solar PV investment supporting schemes. The final section is subject to conclusions and insights for future research.

2 LITERATURE REVIEW OF THE SOLAR INDUSTRY

The solar energy marketplace has experienced tremendous growth over the years. In 2000, the cumulative capacity of installed solar PV was 1.2 gigawatts (GW), but as of the beginning of 2023, it has grown to an impressive 1177 GW [24]. The increased maturity and progress in technology, coupled with a learning curve, have resulted in a 90% decrease in solar electricity costs over the last decade making solar-based measures more cost-effective compared to gas or coal-based solutions of equivalent power output [25, 26]. Considering the levelised cost of electricity (LCOE) in 2023, spending one euro on solar PV returns a ten-fold increase in electricity generation compared to the amount of electricity generated in 2009 [25, 26]. In this regard, the global share of electricity generated by solar power generation installations rose to 4.5% by the beginning of 2023 from only 0,1% in 2010 [27]. Solar power generation within the European Union has also significantly increased from almost 22,000 gigawatt hours (GWh) per annum in 2010 to an annual 216,000 GWh in 2022 [28]. This growth has been attributed to the implementation of stricter regulations [2] aimed at curbing greenhouse gas emissions, which, as a result, relate to EU financing facilities, partial reimbursements of interest rates, tax reductions, and (or) cost coverage schemes consisting of up to 1/3 of the capacity of the installations [29, 30]. Given the context, the EU market for solar panels currently comprises at least 157 manufacturers [31] offering various options (among which monocrystalline ones are recognised as one of the most efficient). For instance, considering the top 5 manufacturers of solar PV panels from 2020 to 2023 [32], it is possible to have even more than 100 models of solar PV panels to choose from (Fig. 1).



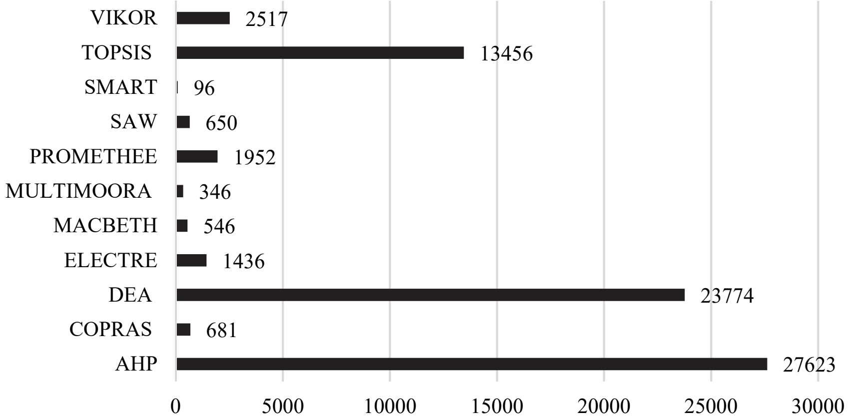
Source: Author, based on analysis of the listed entities; the first six are among the top 10 manufacturers worldwide regarding actual shipments since 2012. The entities are depicted in alphabetical order.

Figure 1 The offerings of the leading solar PV producers (during 2020-2023)

Moreover, besides monocrystalline silicon cells with power generation efficiency rates ranging from 20 - 23% [25], all-perovskite tandem solar cells, as another type of alternative, boasting an efficiency level of 39% [33], are under development. Next, to ensure that a solar system operates efficiently and sustainably, a respective solar power inverter must be chosen to convert electrical current to alternating current. For instance, there could be up to 40 different types of inverters from the top 5 solar PV manufacturers mentioned above [32]. Nevertheless, despite the regulatory incentives and the efficiency rates of solar PV systems, as mentioned above, the metering schemes are among the critical factors when deciding to become a solar prosumer. The net energy metering (NEM) scheme can stimulate solar investments while charging the prosumer based on the electricity market price, i.e., net energy billing (NEB), exposing the latter to the risks subject to fluctuations of electricity prices caused by diverse external factors typically affecting business activities [34]. For example, Poland's NEM scheme, launched in 2016, significantly impacted households' solar capacity growth. The scheme led to an exponential increase in solar capacity from 55 megawatts (MW) in 2015 to an impressive 4774 MW at the beginning of 2023 [28]. However, the transition to an NEB scheme since 2022 charging (based on actual electricity market price) prosumers for the difference in generated and consumed electricity amounts has led to a slowdown in solar PV installations by households. According to the Institute of Renewable Energy of Poland (IRE (2023)) [35], if the first quarter of 2022 saw the installation of 1.3 GW of PV generation capacity from households, by the third quarter of 2022, only 375 MW had been installed by households [35]. As per IRE research [35], concerning the NEB scheme, more rational dimensioning of household PV installations and investments in heat pumps and battery energy storage systems can be observed to manage surplus electricity generated more rationally. In addition, IRE also questions NEM's economic feasibility, stating that under the NEB, the internal rate of return (IRR) is 19% to 25%. At the same time, under the NEM scheme, the prosumer's IRR is just 13% to 14% when considering solar PV installations of 10 kilowatts (kW) capacity [35]. The latter findings could also support Ziras et al. (2021) [36] research on Danish prosumers and the Manuel de Villena et al. (2021) [37] case of Wallonia. Considering the context mentioned above, the next section will overview methods that are viable for reasoning solar setups for prosumers.

3 REVIEW OF MCDM METHODS

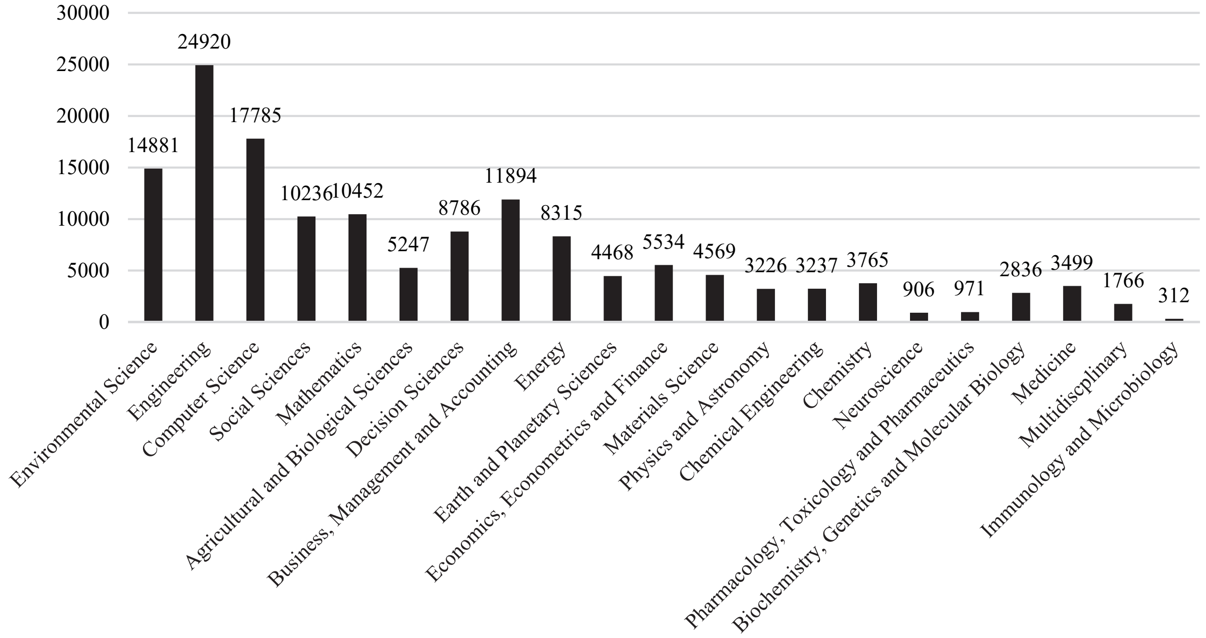
Various MCDM techniques have been thoroughly examined in numerous scientific works on solar photovoltaics (PV). For instance, testing a novel logarithmic additive estimation of weight coefficients (LAAW) under a fuzzy environment to determine the degree of importance of each criterion for solar PV site selection Deveci et al. (2021) [38] noticed 56 related studies, of which 29 used AHP, including 8 that combined AHP with TOPSIS and VIKOR, while other studies used programming solutions and (or) GIS (Geographic Information System). In another case, when investigating cost-effective solutions and choosing the best solar cell for a PV array, Manoj et al. (2023) [39] noted 29 studies on selecting a photovoltaic plant. 12 examples were also related to AHP; others combined TOPSIS, PROMETHEE, and SMART techniques. In this regard, researchers [39] used the VIKOR and TOPSIS techniques together with AHP. Tajik et al. (2023) [9] investigating the selection of materials for li-batteries found 22 studies, of which 11 experiments relied on TOPSIS, while the combinations of VIKOR, AHP, SAW and others characterized the rest. Investigating solar PV plant site selection in Vietnam Wang et al. (2022) [8] revealed 17 studies where combinations of VIKOR, TOPSIS, ELECTRE, AHP, and DEA were used. In conclusion, while AHP is the most often used method, TOPSIS, VIKOR, ELECTRE, DEA, GIS, and their combinations are also frequently found concerning solar-related themes. Based on the data gathered from the whole Scopus database, AHP was also seen as the most common method, along with the DEA and TOPSIS methods (Fig. 2).



Source: gathered from the Scopus database until March 6, 2024. Note: data is limited to scientific articles, except for subjects in the arts and humanities, dentistry, nursing, psychology, health professions, and veterinary medicine.

Figure 2 Total number of scientific articles per MCDM method

However, it is important to highlight that most studies focused on selecting sites for solar PV or power plants and not directly dealing with solar PV panels. Out of 900 research papers reviewed from Elsevier journals in the Scopus database to explore solar PV solutions for individual households, only 6 research articles related to the selection of solar PV installations were found, while 35 were dedicated to site selection aspects. In addition, across the entire Scopus database, only 15 papers on selecting solar PV installations were found out of 8315 papers on energy-related research (Fig. 3).



Source: Data on MCDM methods (Fig. 2) per research subject is gathered from the Scopus database until March 6, 2024.Note: data is limited to scientific articles, except for subjects in the arts and humanities, dentistry, nursing, psychology, health professions, and veterinary medicine.

Figure 3 Total number of articles per research subject

The above data indicate a significant gap in the scientific sources on the segment. Furthermore, the findings concerning MCDM methods revealed that every method has unique strengths and limitations. The advantages of each technique are specific to the criteria and objectives of the decision-making process. However, all methods can have potential drawbacks regarding complexity, time consumption, and the need for expert knowledge. Thus, decision-makers should carefully evaluate each method's characteristics and application specifics before selecting the most appropriate one for their needs. For instance, AHP can be easily applied to decision-making processes, but weighting criteria may influence the final score, and pairwise comparisons can make ranking variables irregular. Moreover, the decision maker's preference can affect the results, leading to variations. It is important to note that changing the available options could lead to a reversed ranking [4, 5]. Concerning TOPSIS, it does not prioritize the correlation of attributes with a Euclidean Distance focus [14]. Thus, the distance to the ideal choice is imperative. Failure to do so may result in unclear decision-making and potentially negative outcomes [14, 15]. Similarly, the VIKOR method has consistency requirements to address weighting and checking, which may be difficult to meet [19, 20]. Additionally, it deals with qualitative values, it is more intricate to apply. The COPRAS method involves a step-by-step process of criteria weighting, normalisation, and ranking, which relies on the decision-maker's subjective assessment. This can make the method more prone to data fluctuations and subjectivity [6, 7]. Applying DEA decision-making units share the same inputs and outputs, but the accuracy of results depends on access to data and its crispiness [4, 8, 9]. This raises concerns about whether the data needed is credible and sufficient, as the latter can impact the accuracy of the results. It is crucial to ensure that the data used in DEA is sufficient and reliable to generate accurate results. In the case of MULTIMOORA, it should be noted that it is a more robust method as it does not require normalization except when processing negative data [6, 10]. On the other hand, SAW requires inputs for criteria values to be positive and maximizing [12, 13]. However, it is important to note that the results obtained from SAW may not always accurately reflect the actual circumstances of a business. This is because SAW assumes that all criteria are equally important and independent of each other, which may not always align with the actual complexities and interdependencies of business operations. Consequently, the potential limitations must be considered when using SAW as a decision-making tool for complex business scenarios. When using the PROMETHEE method, it is important to note that this approach does not offer a solution for weighting or assigning values. This means that to apply the PROMETHEE method effectively, complementary techniques must be used in conjunction [11, 12]. Observations reveal that PROMETHEE and ELECTRE exhibit similarities regarding the number of iterations and outranking. However, the transparency of ELECTRE's process and outcomes could be questionable. Substantiating the outcomes can be challenging because outranking can affect the options' variables [16-18]. Conversely, for instance, the SMART method can be complex in procedure, but it proves relatively user-friendly, provided enough data is available for the decision-makers [40]. Preceding the above context, it has been observed that there are no published articles in the Scopus database that use MACBETH to select photovoltaic installations. However, a significant number of scientific articles using the method for subjects other than photovoltaic installations were found (Fig. 4).

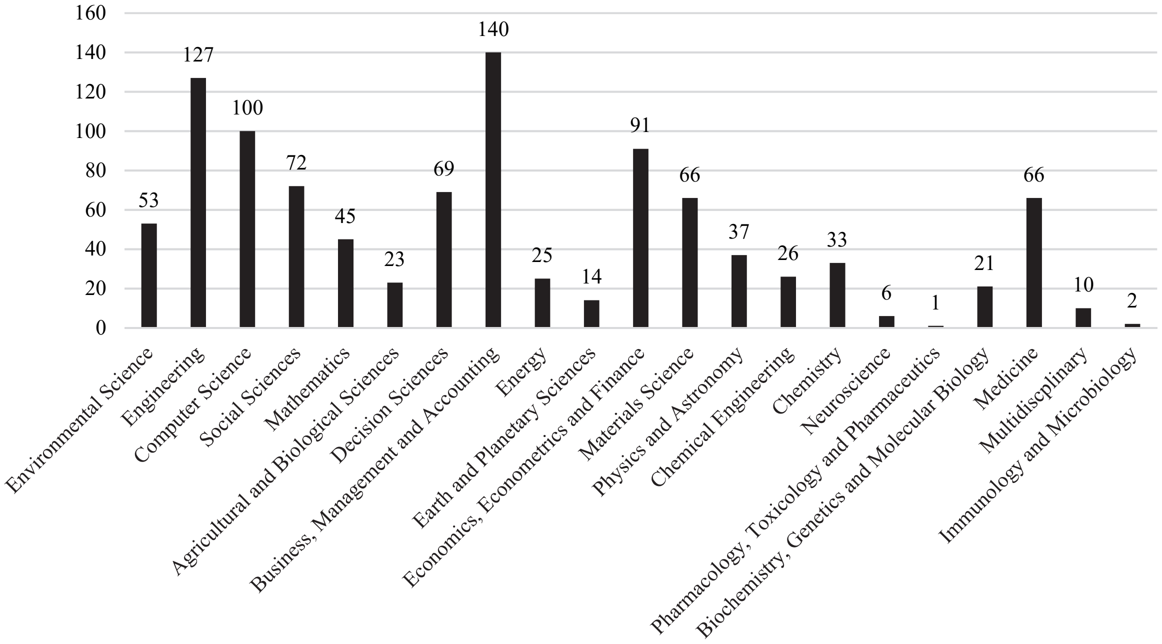


Figure 4 Number of scientific articles using MACBETH per research subject

While MACBETH's appropriateness of applying qualitative judgement can be considered, the latter applied for pairwise comparison using the scale of preference subject to categorical evaluation, thus allowing the measurement of the differences of the utility of alternatives of the solutions and quantifying their attractiveness accordingly. Consequently, no significant shortcomings were explicitly found or addressed by the scholars in that respect. Thus, the findings imply that MACBETH is reasonable for use as it is a simple yet effective way of measuring the attractiveness differences between elements of a specific set. It employs linear programming for weighting and ensures consistency of judgments during the application process [21-23]. Therefore, using MACBETH to decide on the most reasonable (in terms of efficiency and effectiveness) solar PV solution for a prosumer can be considered a rational choice for the MCDM method. The methodology for applying the concerned method to cope with the latter objective is detailed in the subsequent section.

4 THE METHODOLOGY

To improve management and decision-making processes for prosumers when dealing with the variety of PV setups for the rooftop plants available in the market (i.e., Tab. 1), the respective experiment was conducted with Lithuanian prosumers. The MACBETH methodology [21-23] was used in the experiment. Firstly, to form a finite set $A = \{a_1, a_2, \ldots, a_n\}$ of n alternatives (where $A = n \geq 2$), the author requested 23 solar PV suppliers (members of LSE (Lithuanian Solar Energy Association) for turnkey proposals of solar PV system (PV panels & respective inverter (for 10 kW power generation) for the individual household in Vilnius region. We received 19 proposals from 82,6% of the firms that were contacted. These proposals have been detailed by 11 criteria, defined based on the data of the proposals, and listed in descending order by proposal price criterion c_2(€/10 kW), Tab. 1). It is important to note that the proposals have not been ranked yet.

The criteria chosen by the author are reasoned, considering the focus on the economic benefits for the prosumer. Next, the criteria aim to reduce costs while prioritising the solution's utility for the prosumer. The chosen criteria align with the utility theory and cost-benefit analysis approach and are also reflected by the suppliers regarding the potential advantages of the proposals to prosumers. Hereby, the quality and timeline of installation are also critical, in addition to the PV systems' performance efficiency benchmarks declared by suppliers. In this regard, it is important to consider "The timeframe for the installation and operation" (no of days). It was found that suppliers are experiencing a shortage of labor due to the high volume of orders. Thus, proposals indicate a waiting period of 55 to 205 days before the plant is launched. Such contingency results from the demand for photovoltaic installations for households in Lithuania. The latter is sparked by the state's policy of transitioning towards renewable energy sources (RES). The government provides subsidies from 243 EUR (if only solar PV panels are installed, no inverter) to 323 EUR (solar PV panels & inverter) per installed electricity generation capacity for such plants.

In addition, the weather specifics of the region directly weigh on the issues of the timeframe of installation works as well. For instance, according to the actual observations, the energy output for 10 kW PV installation varies between 34 kilowatt-hours (kWh) and 240 kWh during winter. To shorten the payback period, prosumers must have a solar photovoltaic system launched between March and October, whereas, according to actual observations, the average amount of electricity generated varies from 840 kWh to approximately 1800 kWh in spring and between 1700 kWh and 1400 kWh in summer, followed by a decline to 1180 kWh in September down to 166 kWh in November. Continuing with the MACBETH application process [21, -22], the prosumer must compare proposals a_1, a_2, …,

a_{19} (Tab. 1) pairwise, using qualitative judgments to evaluate the attractiveness of alternatives. If the prosumer prefers the proposal a_i more a_j that is, a_iPa_j, if relating the proposals per values $w(a_i)$ and $w(a_j)$. Accordingly, the prosumer concludes that $w(a_i) > w(a_j)$. If $w(a_i) = w(a_j)$, the prosumer could decide that proposal a_i is as good as proposal a_j (i.e., $a_iI\ a_j$). The prosumer compares pairs of proposals $(a_i, a_j) \in A$ using the scale of preference [21-23] listed in Tab. 2.

Table 1 List of proposals

The criterion (c_i) / Proposal (a_i: solar PV panel & inverter names)	The supplier's declared solar PV panel's efficiency (%); (c_1)	Price of proposal (€/10 kW); (c_2)	Solar PV panel operation warranty (No of years); (c_3)	Solar PV panel performance efficiency % after 25 years; (c_4)	Warranty for inverter operation (No of years); (c_5)	The timeframe until system installed & active (No of days); (c_6)	System construc-tionwarranty (No of years); (c_7)	System installation works warranty (No of years); (c_8)	Emergency repairs timeframe (days); (c_9)	Compensation for electricity lost due to system flaws (% of the total amount of electricity lost/day);	Free maintenance services (No/No of years); (c_{11})
a_1 (Canadian Solar & Sofar)	21	6449,73	25	84.8	10	70	10	10	5	No	No
a_2 (Risen & Solis)	20.3	7212,78	15	84.8	10	77	10	10	5	No	No
a_3 (Trinasolar & Foxess)	20.8	7520,00	15	84.8	10	90	10	10	14	No	No
a_4 (Risen & Solplanet)	20.8	7557,60	15	84.8	10	55	10	10	3	No	No
a_5 (Solet & Sofar)	20.97	7632,06	20	84.8	12	90	10	5	1	No	No
a_6 (Hyundai & Growatt)	20.5	7857,14	25	85	10	90	10	10	10	No	No
a_7 (Risen & Foxess)	20.8	7895,74	12	84.8	12	70	10	10	5	No	No
a_8 (Ja Solar & Huawei)	21	7967,48	12	84.8	10	90	10	10	5	No	No
a_9 (Hyundai & Sungrow)	20.4	8048,78	25	85	10	90	10	10	14	No	No
a_{10} (Risen & Sofar)	20.4	8092,48	12	84.8	10	90	10	10	10	No	No
a_{11} (Canadian Solar & Huawei)	21	8102,03	12	84.8	10	150	12	10	5	50%	1/5
a_{12} (Canadian Solar & Huawei)	20.5	8178,37	12	84.8	10	205	10	10	5	No	No
a_{13} (Hyundai & Huawei)	20.4	8480,00	25	85	10	120	20	10	14	No	No
a_{14} (ZnShine & Sungrow)	20.3	8610,00	16	83.33	10	90	10	10	10	No	No
a_{15} (Hyundai & Sungrow)	20.7	8629,22	25	84.9	12	60	10	5	14	No	No
a_{16} (Vertex S & Sofar)	20.8	8634,56	15	84.8	10	150	20	10	5	No	No
a_{17} (Vertex & Huawei)	20.8	8640,00	15	84.8	10	70	10	10	5	No	No
a_{18} (Solitek & Huawei)	19.7	9307,40	30	89.2	10	120	10	10	3	No	No
a_{19} (Sunpower & Huawei)	20.62	9712,75	25	87.2	10	120	15	10	3	No	No

Table 2 Scale of preferences

Type of preference (SC)	Indicator (SC_p)	Scale	Judgement on proposals $a_1, a_2, \dots, a_{19}$ per criterion $c_1, \dots, c_n$ (Tab. 1)
No preference	SC_0	0	No preference over proposals $a_1, \dots, a_{19}$ (i.e., a_{14} I a_{15}) per c_i
Very low	SC_1	1	Very low preference of a_i to a_j that is a_iPa_j per c_i
Low	SC_2	2	Low preference of o_i to a_j that is a_iPa_j per c_i
Moderate	SC_3	3	Moderate preference of a_i to a_j thus a_iPa_j per c_i
Strong	SC_4	4	Strong preference a_i to a_j thus a_iPa_j per c_i
Very strong	SC_5	5	Very strong preference of a_i to a_j thus a_iPa_j per c_i
Extreme	SC_6	6	Extreme preference of a_i to a_j thus a_iPa_j per c_i

The prosumer considers proposal a_i much better than a_j thus $(a_i, a_j) \in SC_4$. Consequently, all the pairs of proposals (a_i, a_j) will be subject to the same set of preferences SC, whereas $w(a_i) - w(a_j)$ will belong to the same range. Then (a_i, a_j), that is a_iPa_j, are associated because adjoining intervals match subsequent types of preferences [21-23], namely as follows (Eq. (1)):

$$a_iP^ka_j : th_p < w(a_i) - w(a_j) < th_{p+1} \tag{1}$$

where $P^{(p)}$ - the preference of value; th_p and th_{p+1} - the value function thresholds (w). Prosumer ensures consistency of the judgments, namely (Eq. (2, 3)) [21-23]:

$$\forall a_i, a_j \in A : w(a_i) > w(a_j) \Leftrightarrow a_iPa_j \tag{2}$$

$$\begin{gathered}\forall p, p^* \in \{1,2,3,4,5,6\}, \forall a_i, a_j, a_z, a_q \in A \text{ with} \\ (a_i, a_j) \in SC_p \text{ and } (a_z, a_q) \in SC_p{}^* : p \geq p^* + 1 \Rightarrow \\ \Rightarrow w(a_i) - w(a_j) \geq w(a_z) - w(a_q)\end{gathered} \tag{3}$$

In case proposal a_i is strongly preferred to proposal a_j that a_iPa_j, then $w(a_i) > w(a_j)$. Correspondingly, when proposal a_i is as attractive as offer a_j that a_iIa_j, then $w(a_i) = w(a_j)$, i. e. $(a_i,a_j) \in SC_0$. Having consistent value preferences $w(n)$ must be minimized, as follows (Eq. (4)):

$$\begin{gathered}\text{Min } w(n) : \forall a_i, a_j \in A : a_iPa_j \Rightarrow \\ \Rightarrow w(a_i) \geq w(a_j) + 1 \text{ ; } \forall a_i, a_j \in A : a_iIa_j \Rightarrow \\ \Rightarrow w(a_i) = w(a_j) \text{ ; } \forall (a_i, a_j), (a_z, a_q) \in A\end{gathered} \tag{4}$$

If the preference of proposal a_i to a_j is more significant than of proposal a_p to a_q, then the following holds: $w(a_i) - w(a_j) \geq w(a_p) - w(a_q) + 1 + \delta(a_i, a_j, a_p, a_q)$; $v(a_i^-) = 0$, where a_n belongs to the set A thus to $\forall\ a_i, a_j, a_p, a_q, \ldots \in A$: $a_n\ (P \cup I)\ a_i, a_j, a_p, a_q, \ldots$,and a_i^- belongs to the set A thus to $\forall\ a_i, a_j, a_p, a_q, \ldots \in A$: $a_i, a_j, a_p, a_q, \ldots (P \cup I)\ a_i^-$; $\delta(a_i, a_j, a_p, a_q)$ is the lowest preference between proposals a_i and a_j as well as between a_p and a_q. Hence, n is the only favourable proposal of set A (i.e., $a_n\ (P \cup I)\ a_i, a_j, a_z, a_q, \ldots$), and a_i^- is the worst proposal in the set A (that is $a_i, a_j, a_z, a_q, \ldots\ (P \cup I)\ a_i^-$). Following the abovementioned procedure, the prosumer must rank the criteria (Tab. 1). Considering every criterion of even significance for the experiment in question, the prosumer then compares the proposals per every criterion. It judges the latter based on the preference scale presented above. To accelerate the execution of this exercise, especially if managing many proposals with the complex and (or) specific data therein, the prosumer can use the respective software application [21, 22]. After evaluating proposals a_1, a_2, …, a_{19} per criterion $c_1, c_2, \ldots, c_n$ the prosumer may decide on the most effective and efficient solution. The evaluation results also can improve the management process for the prosumer of implementing the concerned turnkey contract of solar PV system as to designing the system, the supply of the equipment, timeframe of installation works, and maintenance commitment after completion of the project in question. For example, judging per reimbursement for non-produced electricity due to the system flaws (c_{10}), the gains of proposal a_{11} (the first scenario (based on all 11 criteria), (Tab. 3) could be negligent or reach a few hundred euros if the concerned PV plants were not functioning for months (as to worst case scenario) because of installation and (or) components flaws. Accordingly, the prosumer must enforce the warranties as per c_3, c_5, c_7, and c_8. If the difference in the price of proposals is more than 1600 EUR between the best proposals, namely a_{11} and a_1 (Tab. 1), the benefit of proposal a_{11} per criterion c_{10} could be seen as not generating any significant added value for the prosumer. Also, the value per c_{11} of proposal a_{11} (Tab. 1) can be doubted. In conclusion, the proposals can reasonably be evaluated without considering criteria c_{11} and c_{10}. Thus, if using 9 criteria (i.e., c_1, …, c_9, the second scenario) for assessing proposals, proposal a_1 becomes the best and noticeably outpacing the rest of the proposals compared (Tab. 3). In contrast, as to maintenance requirements, it is sufficient to have the respective inspections once every three years unless there are physical damages, flaws, or related risks. In such cases, the inspection would be required, just activating the relevant warranty commitment as to the above-considered criteria. Hence, proposal a_{11} per criterion c_{11} as per c_{10} does not deliver significant added value to the prosumer.

Table 3 The final ranks & scores

1st scenario				2nd scenario				3rd scenario			
Rank	Proposal	Score	Price of proposal	Rank	Proposal	Score	Price of proposal	Rank	Proposal	Score	Price of proposal
1	a_{11}	60.24	8102.03	1	a_1	70.40	6449.73	1	a_{19}	71.88	9712.75
2	a_1	57.60	6449.73	2	a_4	64.05	7557.6	2	a_1	66.70	6449.73
3	a_4	52.41	7557.6	3	a_{19}	63.90	9712.75	3	a_{18}	63.82	9307.4
4	a_{19}	52.28	9712.75	4	a_7	61.46	7895.74	4	a_4	62.50	7557.6
5	a_7	50.28	7895.74	5	a_5	59.64	7632.06	5	a_7	61.05	7895.74
6	a_5	48.80	7632.06	6	a_{18}	58.77	9307.4	6	a_{16}	60.38	8634.56
7	a_{18}	48.08	9307.4	7	a_{16}	57.10	8634.56	7	a_{17}	59.45	8640
8	a_{16}	46.72	8634.56	8	a_6	56.36	7857.14	8	a_{13}	58.10	8480
9	a_6	46.11	7857.14	9	a_{17}	56.11	8640	9	a_5	57.72	7632.06
10	a_{17}	45.91	8640	10	a_{13}	55.57	8480	10	a_6	55.13	7857.14
11	a_{13}	45.46	8480	11	a_8	55.18	7967.48	11	a_8	54.36	7967.48
12	a_8	45.15	7967.48	12	a_2	52.89	7212.78	12	a_{11}	51.39	8102.03
13	a_2	43.28	7212.78	13	a_{11}	51.40	8102.03	13	a_9	50.91	8048.78
14	a_3	42.00	7520	14	a_3	51.34	7520	14	a_{15}	48.87	8629.22
15	a_9	41.97	8048.78	15	a_9	51.30	8048.78	15	a_3	48.01	7520
16	a_{15}	38.48	8629.22	16	a_{15}	47.04	8629.22	16	a_2	47.37	7212.78
17	a_{10}	35.23	8092.48	17	a_{10}	43.06	8092.48	17	a_{10}	41.82	8092.48
18	a_{12}	32.86	8178.37	18	a_{12}	40.16	8178.37	18	a_{12}	38.94	8178.37
19	a_{14}	30.59	8610	19	a_{14}	37.38	8610	19	a_{14}	37.83	8610

In addition, proposal a_1 also significantly outperforms the closest rivals per c_2. This advantage can be crucial regarding the risks associated with reviewing metering schemes, which occur annually in Lithuania under existing regulations. Also, minor difference per c_1 and c_4, subject to solar PV plant performance, implies that in case of higher prosumer tariffs, related grid charges and higher inter-bank interest rates, the more expensive proposals will be subject to more extended payback periods. This is particularly pertinent if the required investments are funded through a bank loan. Assuming the prosumer seeks only the highest product performance efficiency (the third scenario, i.e., based on 8 criteria, namely, c_1, c_3, …, c_9, in Tab. 3), proposal a_{19} becomes the most attractive, disregarding the risks of changing tariff policy, inter-bank interest rates and other contingency factors affecting the solar PV marketplace. In conclusion, after comparing all three scenarios (Tab. 3), proposal a_1 is the most reasonable choice for the prosumer, considering its associated risks.

5 DISCUSSION

The undermentioned insights can be made from the results of the experiment (section 4). Firstly, analysis of the collected data (Tab. 1) regarding the received proposals indicates a tight solar PV panel efficiency range from 20.3% to 21% (only one proposal was based on 19.7% solar PV panels). This implies close competition among manufacturers in terms of technological advancements. This is an essential argument for the prosumer when seeking and negotiating with the suppliers for a lower price and improving their proposals as to the concerned criteria in the previous section. However, to develop such findings, the prosumers must be qualified to access a wide range of suppliers (as per the experiment). Nevertheless, it can be challenging if the prosumer has no relevant access to the digital data, does not have sufficient computer literacy (or is not appropriately equipped), and (or) needs more knowledge about the concerned market. Secondly, technological advancements may not be sufficient to ensure the shortest payback period on the prosumer's investments. In this respect, the timeframe until the system is installed & active must be as quick as possible to start generating electricity as soon as possible. Thirdly, the price range of the proposals, i.e. from 6449 EUR to 9712 EUR (Tab. 1), where the price of the most expensive proposal is more than 50% higher than the price of the cheapest proposal, may imply possible supply chain limitations per the supplier. The above reflections also reveal information asymmetry, which prosumers need to tackle regarding the rationale of their investment decisions. In this regard, relevant state authorities could apply respective regulatory and administrative measures to set up a database of suppliers to facilitate prosumers' direct access to the latter. The latter is also due to respective government authorities improving the management of public funds dedicated to supporting solar PV investments (as well as other RES-related solutions). Fourth, considering the above insights, the tariff policy (section 2) for solar PV prosumers must also be justified to ensure sustainable development of the solar industry concerning segments of prosumers as manufacturers, not slowing their investments aiming at available potential and further development of related technologies. Fifth, section 4 also reveals that the MACBETH application boasts adaptability and simplicity due to its function of qualitative judgment when dealing with qualitative and quantitative data, which other analysis techniques can complement. As a result, the method in question can support prosumers in decision-making when seeking the most rational choice of solar PV system and contributing to the overall management processes of such projects. Accordingly, relevant state authorities may consider creating web-based, mobile, and computer-based applications to facilitate data collection, evaluation, and selection process for prosumers to decide on the most rational choice. Furthermore, it is appropriate to explore the potential of MACBETH to streamline the procurement process for public organizations and facilitate the allocation of compensations on installed power generation capacity. Lastly, the research findings suggest that applying MACBETH can help suppliers, manufacturers, and market participants identify the advantages and disadvantages of solar PV and improve the competitiveness of their activities and the characteristics of their specific products accordingly.

6 CONCLUSIONS

The ongoing transition towards renewable energy-based power generation solutions is a significant step in addressing the challenges of climate change while meeting the growing demands for electricity. In this respect, expediting the transition process to achieve sustainable economic growth is crucial. One of the solutions to accomplish this objective is transforming households into solar prosumers. In this regard, the research revealed the use of numerous MCDM methods by various scientists to resolve issues related to the development of solar infrastructure among public and private organizations in different countries. However, rare instances that concentrate on selecting solar PV panels for residential use have been identified. Furthermore, MCDM methods are characterized by differences in the algorithms, the criteria used, and the assigned weightings per criterion. Therefore, selecting a particular method or a combination of methods requires vigilant consideration of the benefits and weaknesses of each approach. Given the context, the experiment conducted in Lithuania employed MACBETH because it relied on qualitative judgments, which are critical when precise and clear data needed for decision-making is unavailable. The 19 proposals were evaluated using a qualitative judgment approach to assess differences in attractiveness. The values of the proposals were then quantified, and subsequently ranked to provide a clear indication of the appropriate proposal. Consequently, besides supporting managerial decisions beyond operational and tactical tasks, the method concerned could be applied to solve broader strategic issues related to the sustainable development of private and public organizations in dynamic business landscapes and evolving regulatory systems. For instance, the research found it expedient for relevant state authorities to consider facilitating the selection management process using MACBETH for households tackling information asymmetry to make efficient and effective decisions toward their solar investments. Consequently, the management of the disbursement of state subsidies to stimulate household solar PV investments could be improved. The research results also imply that the method in question could improve the competitiveness of operations of the respective market players and their products. Subsequently, the research results could be utilized in further studies subject to the ongoing transition to renewable energy-based power generation, for instance, concerning the solar PV industry's resistance to changing tariff policies and fiscal and monetary regulations.

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