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Using Multi-Criteria Decision-Making Techniques to Select Criteria in Renewable Energy

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Abstract: With global population increases, there is a noticeable change in pollution levels across the globe. This heightened environmental concern has played a significant role in sparking a growing demand for devices powered by renewable energy. The demand is not only a reflection of rising environmental awareness but is also driven by other factors, including the prospect of lower operating costs that renewable energy options can offer over their non-renewable counterparts. Renewable energy technology is a complex and rapidly evolving field. To effectively manage this growth, it has become crucial to carefully consider all the major parameters and constraints that impact the decision making process. This involves an understanding of technical parameters such as energy efficiency and durability, financial factors and environmental concerns such as the carbon footprint of the energy source. The task of integrating these diverse and often competing factors into a coherent decision making framework can be accomplished using Multi-Criteria Decision-Making (MCDM) techniques. These techniques have proven to be reliable and effective tools for tackling complex decision-making scenarios that involve multiple objectives. MCDM operates by identifying and prioritising the most viable alternatives within the decision space. This is done by considering the influential factors, or parameters and determining their relative importance to the overall decision making process. It should be noted that the application of MCDM is not merely theoretical. The analysis conducted using MCDM approaches incorporates the use of a sophisticated algorithm to deliver tangible and actionable output. The primary objective of this paper is to apply an MCDM approach specifically to the renewable energy technology sector. Further, it aims to identify and highlight the key criteria that are the most essential to the successful implementation and advancement of renewable energy systems.

Keywords: Multi-criteria Decision-making Techniques, Renewable Energy, Optimised Criteria, Decision Space, Selection Criteria

1. Introduction

Energy plays an important role in the economic development of a country, where the survey [1] demonstrated a strong correlation between economic growth and electricity consummation. The overutilisation of fossil fuels has over time led to a significant negative impact on the environment. The report of the Intergovernmental Panel on Climate Change (IPCC) [2] states that by the end of the 21st century there may be an increase of 6 to 7 degrees in the earth's temperature due to increased utilisation of fuels. Choosing alternate sources of energy is a multidimensional decision process that involves different parameters at different levels.

The rises in both population and pollution levels means that there has been increased need for alternate sources of energy. In particular, global energy demand is expected to expand by around 1% compoundly per annum until 20240 [3]. Further, present reports suggest that approximately one billion people across the globe do not have access to electricity [4]. There has however been accelerated progress over the last few decades in moving to renewable sources of energy (Figure 1). Saini et al. [5] demonstrate progress of PV wind microgrids that are specifically for electricity generation. Despite this, the power generated from renewable sources does not yet keep pace with the ever increasing growing demand.

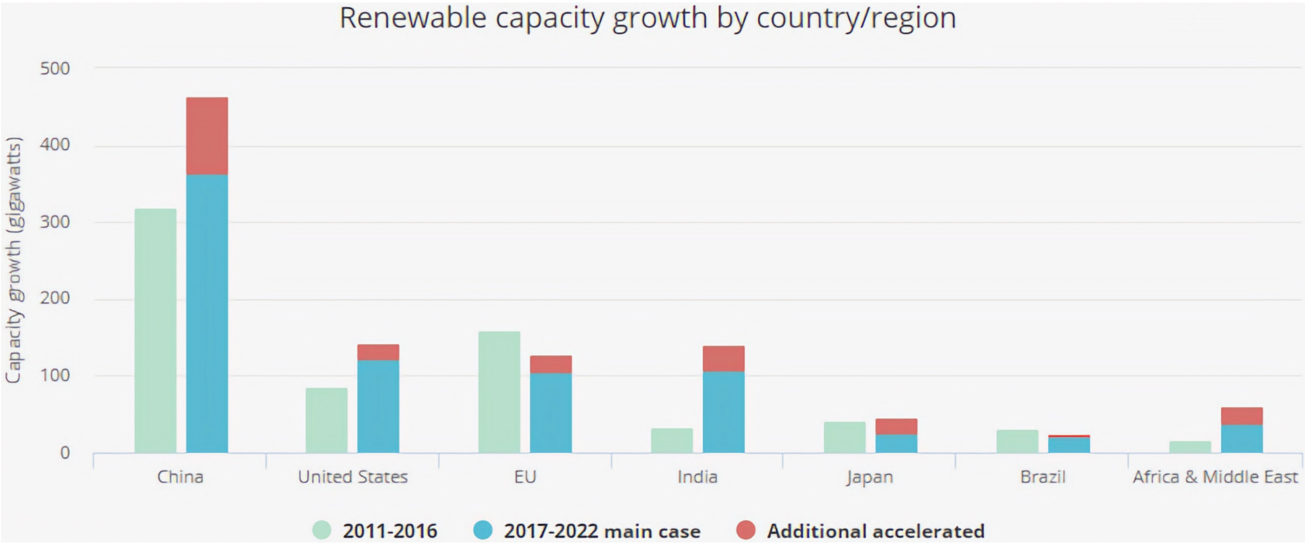

Figure 1. *Adoption of renewable source of energy by different countries [6].*

In order to cope with the climate crisis of environmental sustainability and exhaustion of non-renewable energy, many countries are actively looking for renewable sources of energy production. This transition from traditional fossils to more clean sources of energy is a major challenge faced across the globe.

This shift unsurprisingly impacts heavily on those countries whose economy depend upon the export of fossil fuels. Alizadeh et al. [7] provide a framework for a renewable energy system that includes the identification of the constraints which hinder the use of renewable sources of energy.

Upon designing a policy for renewable sources of energy, their low cost, sustainability and efficiency are key crucial considerations. Solar energy has proven to be one of the most efficient sources of electricity generation. The hazardous effect of conventional sources of energy on the environment has led to the development of green technology. In particular, the development has focuses on looking into energy alternatives to reduce the emission of greenhouse gases [8].

Different renewable technologies are being explored in order to facilitate the increasing demand for sustainable energy [9]. The transport sector for example nearly emits of quarter of total carbon emissions [10]), however, electric vehicles (EVs) have zero emission potential and some EV makers have seen year-on-year demand increases of around 185%.

With such surges in demand, it is necessary that much attention should be given to how such a global surge in demand for electricity is met. Bohanec et al. [11] provide a number of factors that are appropriate in order to select the energy production system.

An increase in the complexity and multiplicity involved in energy planning cannot be resolved by classical single objective optimisation techniques. In consequence, this places a major constraint on decision makers when optimising the available energy alternatives. Further, energy planning at set-up becomes more complicated due to topographical and geographical constraints [12]. Hence, MCDM tools were considered as an unbiased evaluation tool to resolve these constraints.

Qian et al. [13] implemented Fuzzy AHP and TOPSIS for the production location of Photovoltaic Energy and Solar Thermal Energy. Wang et al. [14] performed an analysis based on the investment cost, CO_2 emissions efficiency, maintenance cost, land use and job creation. The purpose of the paper is to reduce the gap existing in literature by providing a set of parameters to develop a framework for the selection of solar panel by assigning a weight to evaluate the factors for standard dominance.

2. Why Solar Energy

The ability of photovoltaic cells to convert the solar radiations directly into electricity make photovoltaics (PV) a future of the world of renewable energy technology. As the photovoltaics acquires the energy in decentralised way, it contributes in sustainable production of energy. In present scenario there are two types of PV panels i.e., monocrystalline and poly crystalline PV panels available for installation. Due to presence of more crystals embedded in monocrystalline panel, it is more efficient and quite expansive too. The statistics of 2022 indicates that (Figure 2) China is at the top in the production of renewable source of energy, using wind as one of its major sources. Europe achieve a first position in the production of solar energy. Data indicates that by as early as 2023, Europe could replace non-conventional source of energy by conventional energy.

The ever-increasing growing population and increasing environmental pollution made a paradigm shift of traditional energy sources to the renewable one (Figure 3). The installation of panels not only reduces the electricity cost but contributes to sustainable environment. Moreover, in present era people are switching to the electric vehicles due to the soar in the prices of fuels. Thus, the paper contributes significantly to identify the parameters of PV panels available in the market, their efficiency and develop a mathematical model to identify the optimality of these parameters.

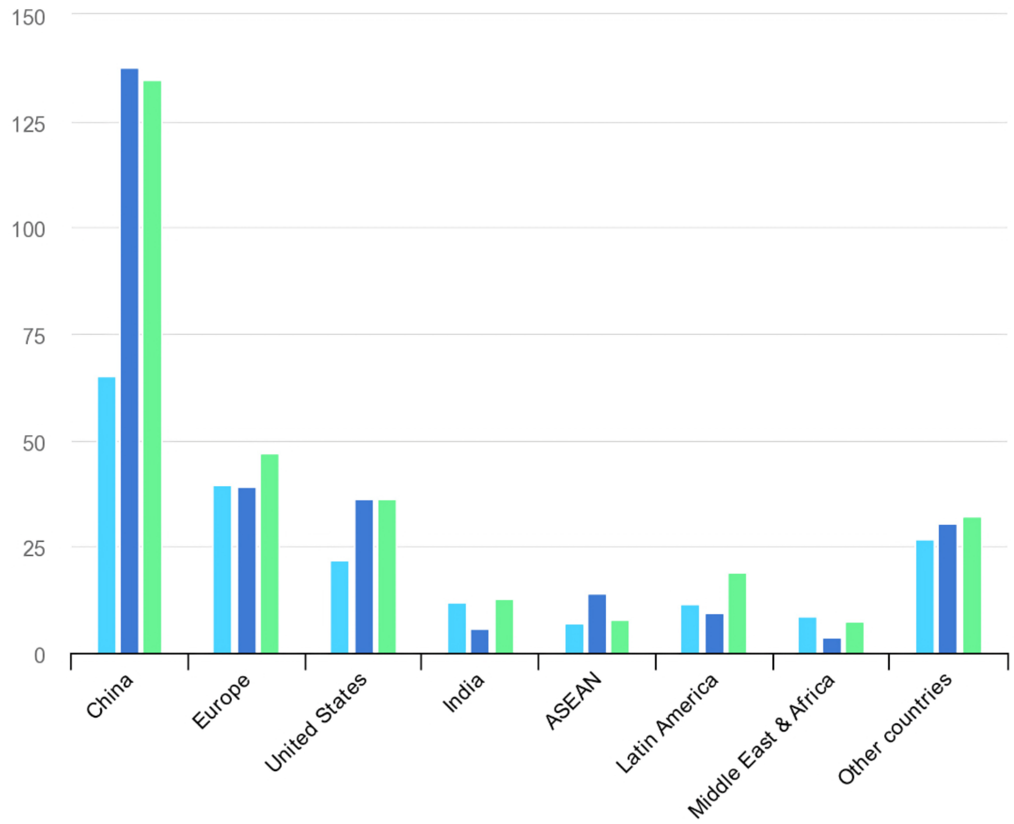

Figure 2. *Energy Production across the Globe in 2022 [15].*

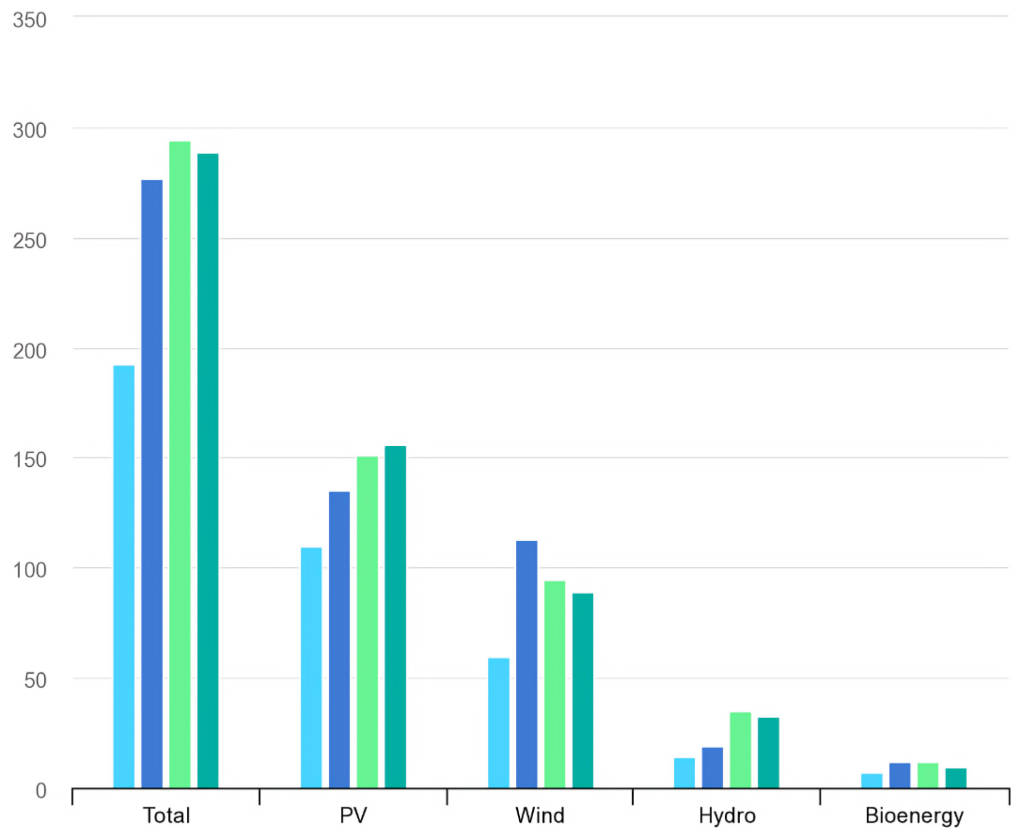

Figure 3. *Renewable source of energy production in 2022 [15].*

3. Mathematical Analysis

Multi-Criteria Decision-Making (MCDM) is an appropriate tool in order to analyse the different criteria and alternatives defined in decision space. This is a mathematical approach that considers multiple criteria and provides a way to order them depending on their role in the decision making. MCDM approaches additionally provide tools to deal with multiple (perhaps) conflicting objectives, different forms of data and a large number of criteria. In particular, the methodology presented here provides a solution to increase the complex energy management system.

Traditional programming approaches such as linear and integer linear programming identify the optimal output at minimum (or maximum) cost. In light of the inherent complexity of sustainability problems, there is a need to consider multiple objectives within one overarching framework. MCDM techniques are in consequence used to consider available criteria and alternatives defined in decision space.

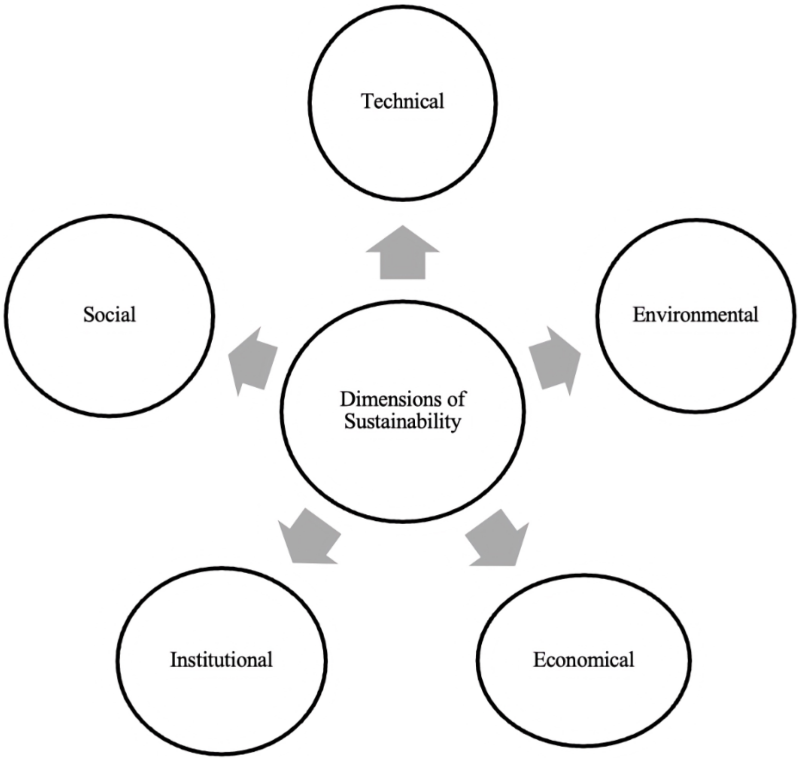

Figure 4. *Key parameters of sustainability for electrification.*

Ilskog [16] define five dimensions of sustainability, illustrated in Figure 4. The variance from the above sustainability parameters yields the inclusion of one additional parameter, namely a technical aspect that focuses to facilitate the proper electrification of the system. These indicators of sustainability are taken under consideration by reviewing the previous literature.

This sustainability is then further ranked based on the sub-parameters [14], given below (Table 1). Many researchers have used these criteria in order to evaluate the sustainability of renewable systems.

Table 1. *Evaluation criteria for renewable source system.*

Technical	Economic	Environmental	Social
Energy efficiency	Investment cost	Emission of gases	Social benefits
Safety	Operational cost	Emission of articles	Employability
Reliability	Fuel cost	Land-use	
Primary energy ratio	Electric cost	Noise pollution	

Depending on the number of alternatives the differences can be highlighted between Multi Attribute Decision making (MADM) and Multi Objective Decision Making (MODM). MODM is an appropriate approach to evaluate continuous alternatives for which we define constraints in the form of vector decision variables. An optimal output is obtained by considering the set of alternatives that undergo the analysis by degrading the performance of one or more objectives. MADM makes [17] the decision over the available alternatives that are characterized by multiple attributes defined in decision space. Different MCDM techniques are employed by researchers in the field of renewable energy to know the preference of the criteria and the available alternatives over the other. In this paper, the comparative analysis of different MCDM techniques is carried out in order to evaluate the optimal alternatives among the set of defined alternatives.

More formally, MCDM techniques support the rational decision making which results in getting an optimized output by undertaking the problem constraints, namely

$$\begin{aligned} \text{minimise} \quad & F(\boldsymbol{x}) = (f_1(\boldsymbol{x}), f_2(\boldsymbol{x}), \ldots, f_k(\boldsymbol{x}))^T \\ \text{subject to} \quad & g_i(\boldsymbol{x}) \geq 0 \quad \text{for } i = 1, 2, \ldots, n \\ & x_i \geq 0 \quad \text{for } i = 1, 2, \ldots, n, \end{aligned}$$

where $\boldsymbol{x} = (x_1, x_2, \ldots, x_n)^T \in \mathbb{R}^n$ is n-dimensional vector of decision variables. The inequalities are constraining the model for each i, while, the objective function is a vector of the parameters for the selection of attributes of PV panels.

Hence, MCDM tools have become a popular tool in energy planning since it supports the decision-makers to formally evaluating criteria defined in the decision space and rank them based on the decided priority in the space. In order to maximise the probability that a correct decision is made and to provide an optimal energy plan it is preferable to take a large set of criteria that are defined in some decision space. Intuitively, the larger the set of criteria used will increase the likelihood that a correct decision is made, however, this will be at the cost of significant increases in computation time. Further, MCDM techniques can help the decision maker quantify the criteria depending on its importance in decision making.

This research work gives a brief about different MCDM techniques and provides insight into energy planning based on renewable energy sources, where we focus primarily on solar energy. The MCDM techniques formulated in the research work used to find out the optimal solution to the energy system design involving multiple and (perhaps) conflicting objectives. Ranking of technologies in order to find the most optimized factor that impact the decision-making influence the relative importance of the determinant importance of the parameters in decision making.

4. Selection Criteria

The standard deviation and entropy method (Table 2) is used for assigning a weight to different criteria defined in decision space. The weights are assigned to some criteria before then evaluating their importance in the decision making. The value of the weights assigned to the criteria depends on the nature of the given criterion, the dispersion of choice performance, the objective uncertainty and the analysis done by decision makers when deal with small differences in alternatives.

The standard deviation method determines the target related to the alternatives which are defined in decision space [18]. Depending on the benefit and cost targets, a normalised matrix is then formulated. For each objective, the standard deviation is calculated [19].

Table 2. *Weights assigned to select parameters using the standard deviation and entropy methods.*

Attributes	Standard Deviation Method	Entropy Method
PV efficiency	0.040540	0.077422
PV lifetime	0.0767126	0.011123
Total power generation	0.023082	0.027539
PV panel cost	0.009138	0.487074
Battery cost	0.0758723	0.384587
Hourly self-discharge rate	0.774653	0.012256

Figure 5 below illustrates that for the selection of PV panel all the parameters “significantly” contribute to decision making. Weights is assigned to the attributes to remove the biasness in decision making and to get an optimal output. The graph indicates that there are significant differences in few parameters in the selection of solar panels. Note that some of the parameters such as generation of power does not show the deviation in the assigned weights.

Figure 5 indicates the weights assigned to the decision parameters chosen to select the PV panel depending on the different attributes. The weights assigned to the attributes evaluate the data on the same scale resulting in the reduction of bias.

In this paper TOPSIS and MOORA are used to check the accessibility of the results. TOPSIS is one of the MCDM tool that rank the alternatives by calculating the distance from both positive and negative ideal solution simultaneously. The optimal alternative is determined by the highest closeness coefficient. According to TOPSIS algorithm the normalized matrix is formulated.

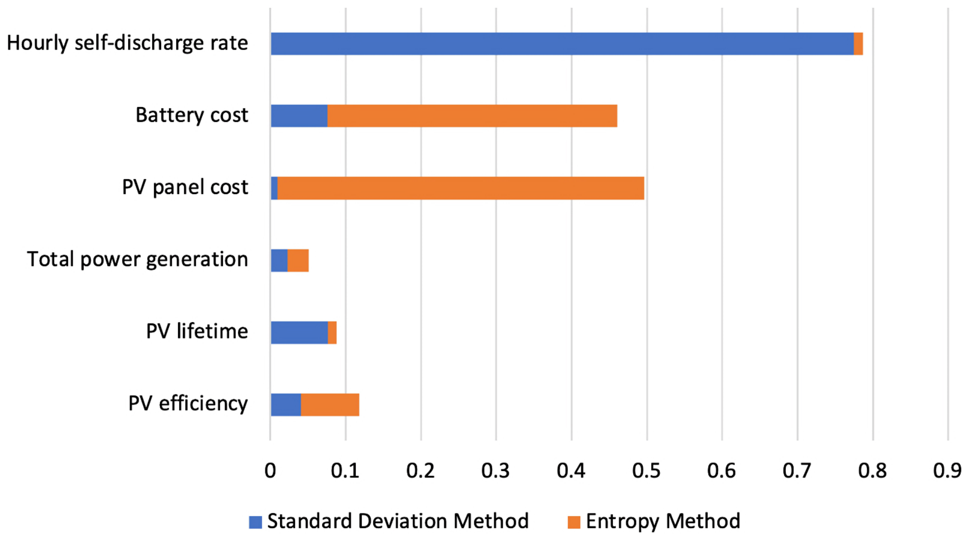

Figure 5. *Weights assigned to attributes.*

Table 3. *Rank assigned to the alternatives by TOPSIS and MOORA.*

	TOPSIS				MOORA	
Alternatives	**Si+**	**Si-**	**Ci**	**Rank**	**Augmented Matrix**	**Rank**
A1	0.022217	0.020747	0.482891	25	-0.1428	23
A2	0.012274	0.022345	0.645451	7	-0.13549	8
A3	0.012967	0.019885	0.605284	11	-0.13812	15
A4	0.008079	0.024527	0.752216	3	-0.13026	4
A5	0.012585	0.019926	0.612896	10	-0.13661	13
A6	0.022283	0.016468	0.424979	29	-0.15055	29
A7	0.013431	0.021769	0.618429	8	-0.13642	11
A8	0.01418	0.017799	0.556584	16	-0.14056	18
A9	0.016049	0.019799	0.552307	18	-0.14046	17
A10	0.01729	0.017507	0.503112	23	-0.14313	25
A11	0.016688	0.019104	0.533753	20	-0.14189	22
A12	0.006458	0.024918	0.79417	2	-0.12823	2
A13	0.017691	0.013588	0.434419	27	-0.14569	27
A14	0.015075	0.017349	0.535054	19	-0.14131	20
A15	0.01603	0.015786	0.496174	24	-0.14292	24
A16	0.013675	0.019851	0.5921	14	-0.13784	14
A17	0.011343	0.02111	0.650492	6	-0.13516	6
A18	0.012627	0.020347	0.617062	9	-0.13605	9
A19	0.013601	0.020668	0.603106	12	-0.1354	7
A20	0.003054	0.027819	0.901089	1	-0.12368	1
A21	0.022062	0.012702	0.365369	30	-0.15109	30
A22	0.015799	0.019561	0.553203	17	-0.13984	16
A23	0.010791	0.023432	0.684676	5	-0.13173	5
A24	0.016133	0.023225	0.590093	15	-0.13661	12
A25	0.014552	0.021532	0.596723	13	-0.13634	10
A26	0.01991	0.018212	0.47773	26	-0.14431	26
A27	0.017602	0.018994	0.519016	21	-0.14084	19
A28	0.007796	0.023441	0.750422	4	-0.12927	3
A29	0.020914	0.0158	0.430357	28	-0.14697	28
A30	0.02023	0.02074	0.506227	22	-0.14162	21

5. Results and Discussions

In this paper TOPSIS and MOORA are used to check the accessibility of the results. TOPSIS is one of the MCDM tool that rank the alternatives by calculating the distance from both positive and negative ideal solution simultaneously. The optimal alternative is determined by the highest closeness coefficient. According to TOPSIS algorithm the normalized matrix is formulated.

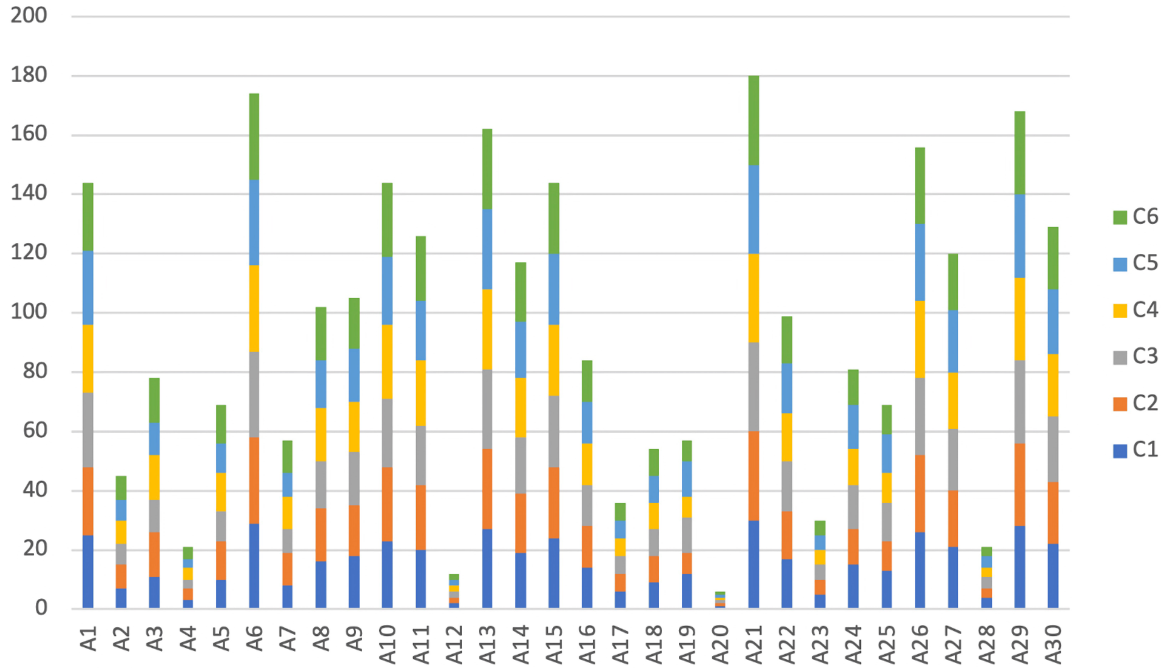

Figure 6. *Comparison of MCDM Technique.*

The competency of conventional sources depends directly on their geographical location and the ambient weather conditions. Thus, for the evaluation of such parameters, the application of MCDM techniques is the most appropriate tool. These approaches are often facilitated to choose the correct alternatives which are conflicting in nature and available for the decision space depending on different criteria. In order to adopt the most optimized alternative inter and intra-comparison of techniques is being carried out [20].

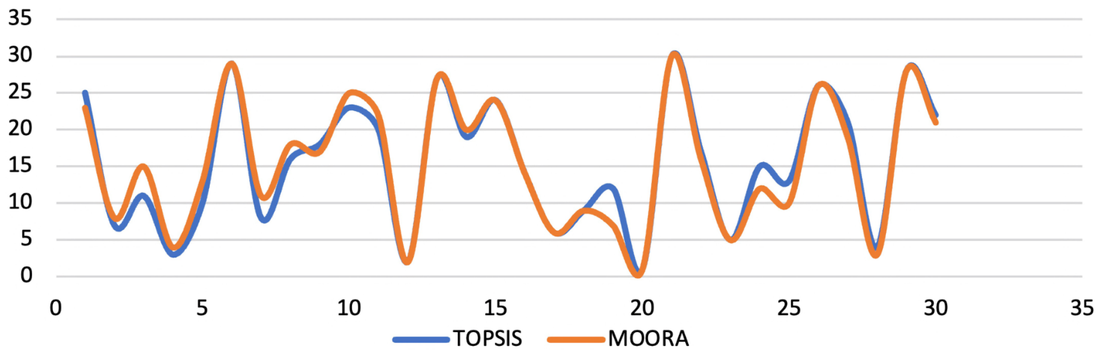

Figure 7. *Comparison of MCDM Technique.*

In comparison with more conventional classical sources of energy, renewable energy provides a clean and theoretically inexhaustible form of energy. Despite this, there are obstacles that make it difficult for renewable energy sources to currently complete with conventional sources. It is for example more challenging to manage the variable supply from renewable sources in order to meet demand. Further, for example the sunk costs associated with a renewable system can be higher in some geographical areas.

For solar PV modelling, researchers have previously considered the constant parameters such as ideality factor, series and shunt resistance. The differences in the results were observed as all these parameters changes with temperature and insulation [21]. The result of the model indicates (Figure 7) that both the techniques rank the same alternative A_{20} as 1 depending on the parameters defined in decision space. It can be observed that the highest impact criteria impacting the preference value is C_5 (discharge rate of PV panel) and the second criterion in terms of local importance is lifetime of PV panel (Figure 5). Thus, it gives a valid explanation why the MCDM techniques order the alternative A_{20} as 1. For entropy method the weights assign to different criteria as compared to that of standard deviation method. The criterion of PV panel cost and battery cost involved in decision making of optimal solution.

6. Conclusion and Future Work

In conclusion, due to noticeable changes in pollution levels, there has been an increasing need for understanding how all the major parameters and constraints impact upon decision making. MCDM techniques provide an approach to integrate these various and sometimes contradictory elements into a cohesive decision-making structure. We have applied an MCDM approach specifically to the renewable energy sector. Further, in this paper we both identify and highlight the key criteria that are the most essential to the successful implementation and advancement of a renewable energy system. In particular, the standard deviation and entropy methods have been used for assigning a weight to different criteria which are defined in decision space. The TOPSIS and MOORA tools are then utilised in order to check the accessibility of the results. There is significant potential for further exploration and research within this field. It would be interesting to for example consider how other MCDM techniques can be applied across other parts of the decision making process. One such example is to explore how the ϵ-Constraint (see e.g. [22, Section 4.1]) or hybrid (see e.g. [22, Section 4.2]) methods could be utilised for selecting locations (and types) of battery where there are multiple contradictory objectives, including minimising costs and carbon emissions associated with the project while additionally maximising the capacity of those batteries across locations.

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