C6 ACTIVE DISTRIBUTION SYSTEMS AND DISTRIBUTED ENERGY RESOURCES

PS1 - DER Solutions and Experiences for Energy Transition and Decarbonisation

Paper ID_2022: 10768

Sustainable Generation Expansion Planning (GEP) with renewables: A case study of Bahrain

Abdulla ALABBASI[a,b]*, Matthew LEACH[a], Jhuma SADHUKHAN[a], Mohammed SANDUK[c]

a Centre for Environment and Sustainability, University of Surrey, United Kingdom

b Bahrain Center for Strategic, International and Energy Studies, Riffa, Kingdom of Bahrain

c Chemical Engineering Department, University of Surrey, United Kingdom

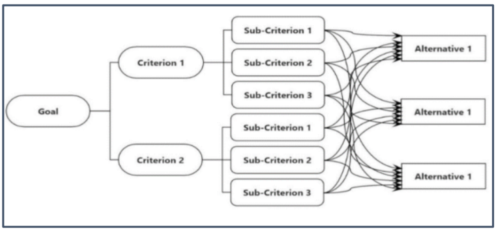
Email: aalabbasi@derasat.org.bh

Motivation

- Bahrain's government has taken several steps to incorporate renewable energy in its energy mix. A significant milestone was achieved in January 2017, when the Sustainable Energy unit (SEU) launched the National Renewable Energy Action Plan (NREAP).
- Although Bahrain's government launched its NREAP, still more rigorous and detailed plans are required to partially decarbonise the power generation sector and increase its security (Naumann et al., 2018). For this reason, it is essential to draw attention to the power system planning activities and how increasing shares of renewable energy adds more technical and economic complexity, as well as changing policy goals.
- The planning process has placed greater emphasis on environmental protection and societal outcomes, which makes the problem increasingly multidisciplinary.
- The Analytical Hierarchy Process (AHP), which is a well-established multicriteria decision making (MCDM) method, is implemented to evaluate and rank the renewable energy technologies for large-scale generation on available land in Bahrain, by considering the relevant technical, social, economic, and environmental criteria

Method/Approach

- MCDM method is selected for this research due to its ability to include different dimensions with conflicting objectives. This method is a branch of operational research aimed at obtaining the best outcomes for complicated conditions based on various criteria and conflicting objectives.
- The AHP is selected for use in conducting the renewable energy generation planning in Bahrain since this method has the following characteristics: Firstly, the AHP can handle both qualitative and quantitative data and help reach a decision based on consensus (Kumar et al., 2017). Secondly, it can lead the decision-makers to find an optimal solution that satisfies different objectives rather than a single target. Thirdly, this method assists in quantifying the weight of the evaluated criterion to a numerical form, which identifies the relative importance of every criterion with respect to the main goal. Finally, the AHP method includes the calculation of an inconsistency index, which allows decision-makers to examine the consistency of their preferences (Mirjat et al., 2018).



$$M = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{in} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix}$$

$$(a_{ii'}) \approx \frac{w_i}{w_{i'}} \quad \forall i, i'$$

$$M = \begin{pmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_i/w_1 & w_i/w_2 & \cdots & w_i/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{pmatrix}$$

$$M = \begin{pmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{in}} & \frac{1}{a_{2n}} & \cdots & 1 \end{pmatrix}$$

$$Final\ (W) = \sum_{i=1}^{i=n} \sum_{j=1}^{j=N} (C_i \times S_{i,j} \times A_{k,i,j}), \qquad \forall k \in K$$

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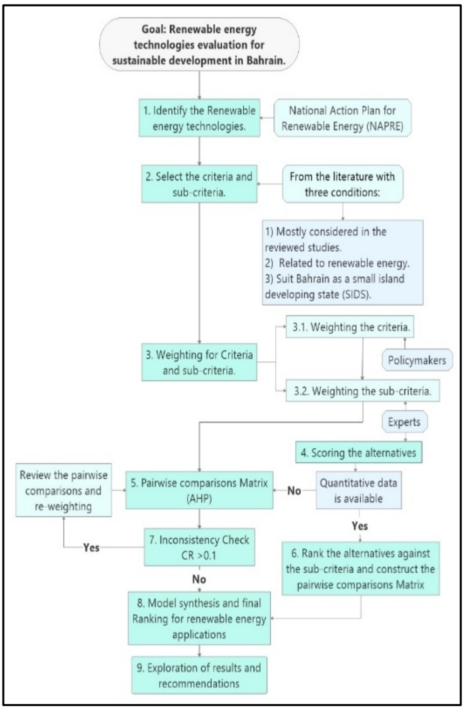


CRITERIA	SUB-CRITERIA	DESCRIPTION
TECHNICAL	Resource availability.	It measures the generation potential for each renewable resources.
	Efficiency.	It determines the different efficiency levels for the selected technologies
	Reliability.	It evaluates the capability of each technology to execute as intended under different scenarios.
	Maturity.	It indicates the period that each technology is tested and then made available commercially and internationally.
	Grid compatibility.	It measures the impact of the chosen renewable energy on the national electrical grid.

CRITERIA	SUB-CRITERIA	DESCRIPTION
ECONOMIC	Investment cost.	It includes the total expenditure required for establishing a plant with its equipment, labour, installation, and commissioning cost.
	Operations and maintenance cost.	It consists of the plant running cost, which includes the cost of the parts for maintenance as well as the employees' salaries.
	Electricity cost.	It measures the predictable cost of electricity generated by a power plant during its lifetime.
	Contribution to the economy.	It evaluates to what extent the national economy could benefit from each technology.

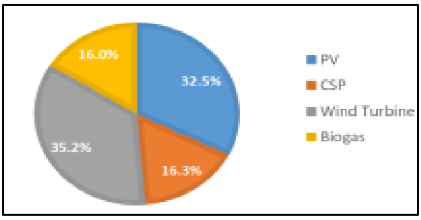
CRITERIA	SUB-CRITERIA	DESCRIPTION
SOCIAL	Employment creation.	It evaluates the potential for each technology during its lifetime to promote job creation.
	Social adaptability	It measures the willingness of customers to change their consumption habits to be more in line with renewable energy characteristics.
	Social benefits.	It indicates the social progress in society and its influence on education, science, culture.

CRITERIA	SUB-CRITERIA	DESCRIPTION
ENVIRONMENTAL	Land requirement	It determines the required land for power plant installation, which varies from application to others.
	Compliance with local natural conditions	It measures the suitability of the selected technology to the country's ecosystem.
	Impact on emission level	It indicates the level of avoided emissions from each application in comparison to the electricity system under analysis.

Discussion

- The results are based on the opinions of policymakers and experts in weighting the criteria and the sub-criteria as well as scoring of some sub-criteria concerning the chosen renewable energy technologies. The rest of the scoring of sub-criteria is obtained through the literature review, and the pairwise matrix is restructured for the AHP model, as explained in the equations.
- There were 75 total responses to the questionnaire and 71 individual participants. Due to the correlation between some of the participants' field of expertise, some participants were asked to cover more than one dimension. The responses to the questionnaire were distributed as follows: 15 policymakers' responses for criteria weighing and 60 experts' responses (technical (15), economic (15), environmental (15) and social (15)) for weighting and scoring each technical, economic, environmental, and social sub-criterion. The chosen policymakers cover different governmental agencies and elected officials.

Overall Priority



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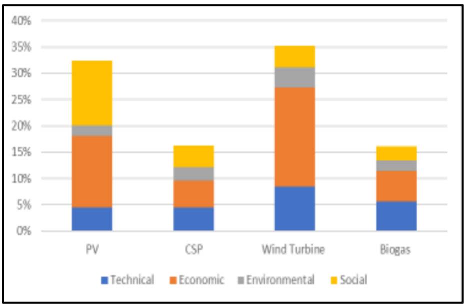
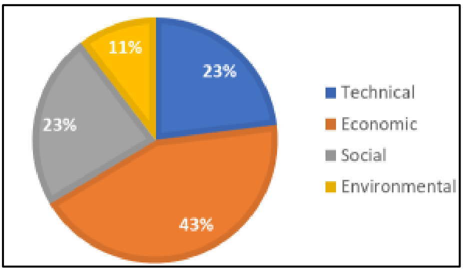
Priority of the Renewable Energy



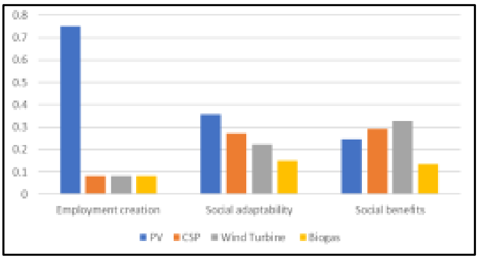
Scenarios of policymakers' priorities

	Scenarios	*Ranking* 1	2	3	4
1	Obtained data	Wind turbine	PV	CSP	Biogas
2	Technical	Wind turbine	Biogas	PV	CSP
3	Economic	Wind turbine	PV	Biogas	CSP
4	Environmental	Wind turbine	CSP	PV	Biogas
5	Social	PV	CSP	Wind turbine	Biogas
6	Tech-Econ	Wind turbine	PV	Biogas	CSP
7	Tech-Enviro	Wind turbine	CSP	Biogas	PV
8	Tech-Social	PV	Wind turbine	CSP	Biogas
9	Econ- Enviro	Wind turbine	PV	CSP	Biogas
10	Econ-Social	PV	Wind turbine	CSP	Biogas
11	Enviro-Social	PV	Wind turbine	CSP	Biogas
12	Tech-Econ-Enviro	Wind turbine	PV	Biogas	CSP
13	Tech-Econ - Social	PV	Wind turbine	CSP	Biogas
14	Econ- Enviro-Social	PV	Wind turbine	CSP	Biogas
15	Tech-Econ-Enviro- Social	Wind turbine	PV	CSP	Biogas

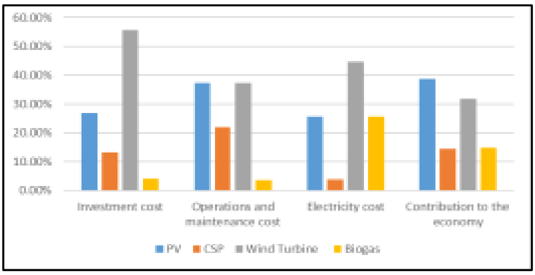
Criteria Weighting



PV and social dimension



Scoring of the Selected Renewable Energy



Conclusion

- This study explores the most promising renewable technologies in Bahrain by considering the sustainable growth of the electrical system. Additionally, it sets the groundwork for further detailed plans and policies for integrating renewable energy technologies into the country's energy mix.
- The results of the AHP model show that wind turbines are the most sustainable technology for Bahrain, followed by photovoltaics. Then, the third- and fourth-ranking technologies are CSP and biogas, respectively.
- The scenarios of policymakers' priorities are implemented to examine the effect of every possible scenario in the AHP model, and the outcome revealed that the obtained ranking is the most balanced one. Furthermore, the analysis showed that some renewable technologies could be more effective than others in tackling a specific challenge