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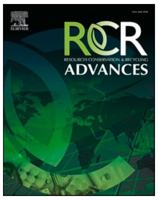

Modelling the drivers of solar energy development in an emerging economy: Implications for sustainable development goals

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ABSTRACT

Energy demand in Bangladesh is consistently rising due to the country's rapid population growth and economic expansion. As a result, solar energy holds substantial potential in the Bangladeshi energy portfolio. This study aims to identify and evaluate the key drivers behind the sustainable development of solar energy in Bangladesh, an emerging economy in South Asia. We do this by adopting an integrated methodology. First, through a literature review and expert feedback, we identify 12 drivers of solar energy development. We then employ the best-worst method (BWM) to rank the drivers based on their significance and use the ISM-MICMAC to analyze the interrelationships among them. The findings indicate that favourable geographical location in terms of solar irradiation, government policy toward sustainable renewable energy, the need to reduce greenhouse gas emissions, and large bodies of water constitute the most significant drivers behind the sustainable development of solar energy in Bangladesh. This research is expected to contribute to the literature on sustainable solar energy development in a systematic way that can benefit both decision-makers and end-users.

1. Introduction

Bangladesh hosts one of the world's most rapidly growing economies. This economic expansion is largely dependent on long-term energy security, which has been strained due to the doubling of energy consumption between 2005 and 2016 (Power System Master Plan 2016, 2016). Bangladesh's burgeoning population facilitates this soaring energy demand, which, in turn, strains existing energy sources. In order to meet rising energy demand and maintain economic growth, Bangladesh must expand its power-generation capacity in a substantial but sustainable manner. As a country that is extremely susceptible to climate change, Bangladesh should ideally enhance its power-generation capacity without producing significant negative environmental externalities. Therefore, sustainable renewable energy (SRE) sources constitute the most logical choice.

Among the many sustainable renewable energy sources, solar energy has the greatest potential in the context of Bangladesh (Liza et al., 2020), which is located perfectly for effectively harnessing sunlight (Nurunnabi et al., 2018). In addition to being environmentally friendly, inexhaustible, and easily expandable, solar energy is highly flexible and increasingly low-cost, making it a promising option for sustainable energy (Kumar et al., 2019). The economic shock brought about by COVID-19 demonstrates that we must treat our planet with more care and respect; the use of renewable energy is one way in which we can demonstrate this respect (D'Adamo et al., 2020).

Coal-based power is notorious for its immense environmental costs and grave health concerns. A major by-product of coal-fired power stations is coal ash—a mixture of airborne fly ash and heavy sedimentary ash, both of which are serious carcinogens (Whiteside & Herndon, 2018; Zierold & Odoh, 2020). Nuclear power plants also carry with them serious safety, health, and stability risks (Hirose, 2012; Yoshida & Takahashi, 2012; Jenkins et al., 2020). None can forget the horrors of the Chernobyl and Fukushima nuclear plant disasters. Finally, the fragility of reliance on imported power points to a clear lack of sustainability. As the world is going through the COVID-19 pandemic, Bangladesh must make a decisive shift toward a more environmentally

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friendly path and boost the long-term sustainability of its energy sector.

According to Nicholas and Ahmed (2020), the current Bangladeshi capacity-expansion plans in the Revisited Power System Master Plan, if implemented, are highly likely to result in substantial overcapacity by 2030. This could come alongside a significant drop in overall demand if the COVID-19 pandemic or any other crisis leads to a sustained global recession. Such dynamics could result in a severe financial burden stemming from the need to maintain the availability of idle plants. Thus, it would be pragmatic for Bangladesh to consider solar energy, as it would enable the country to avoid reliance on costly imported coal and LNG with high tariffs and subsidies.

In 2019, global GHG emissions increased for the third consecutive year, hitting a new record of 59.1 GtCO2e (UNEP, 2020). The global warming brought about by this increase, contributes to the rising sea level, which constitutes a severe threat to the low-lying coastal nation of Bangladesh. Hence, it is imperative for Bangladesh—alongside the rest of the world—to diversify its energy sourcing and move away from its reliance on fossil fuels. Applications like rooftop solar panels, solar irrigation systems, solar water pumps, night lights, and utility-scale solar parks have massive adoption potential in this country. Additionally, the abundance of large bodies of water in Bangladesh represents an opportunity to install floating solar photovoltaic (FSPV) plants.

Not many researches have been done so far on the development of sustainable solar energy in developing countries. However, various researchers have explored the area of sustainable renewable energy in a broader sense. Melnyk et al. (2020) analyzed the impact of key social and economic drivers of renewable energy in the developed North American and European countries. The study found that the gross domestic production (GDP) per capita has a negative relation with the growth of the renewable energy sector negatively. Ali Sadat et al. (2021) used a fuzzy AHP-TOPSIS method to assess the barriers to Iran's Solar energy sector growth and to determine the possible ways to overcome the challenges. It shows that "disorganized economic condition" and "inefficient bureaucracy" are the biggest barriers hindering the development of PV energy generation in Iran. Meenual and Usapein (2021) have explored the drivers of microgrid policy in Thailand as the promotion of renewable energy. Qarnain et al. (2021) used a Best Worst Method (BWM) to analyze the key factors that drive the energy efficiency in residential buildings in southern India.

In order to successfully promote the integration of SRE sources like solar energy in the national grid, we must identify and analyze the key drivers behind the development of the Bangladeshi solar energy industry. While many studies have assessed the drivers of solar energy development (e.g., Zhang et al., 2011; Ohunakin et al., 2014; Do et al., 2020; Kwan, 2021), only one has done so in the context of Bangladesh (Marzia et al., 2018), and this study did not prioritize the drivers based on their level of impact. Thereby, evidently, there is still no significant research on the identification and prioritization of the drivers of the sustainable solar energy development in the emerging economy perspective, which presents a clear reserch gap. This reserch, hence, intends to address rhis gap in the literature from a decision analysis perspective. Thus, the main objectives of this study are:

1 To identify the key drivers behind the development of the solar energy sector in Bangladesh.
2 To rank them based on their level of influence, and to explore the interrelationships among them.

We identify the key drivers through a literature review and expert opinions. We then determine each driver's importance by calculating their weight using the best-worst method (BWM). Furthermore, as these drivers do not influence the development of solar energy independently—they interact with other drivers—we assess the interrelationships among them using interpretive structural modelling (ISM) with cross-impact matrix multiplication applied to classification (MICMAC).

This integrated decision-making method is expected to aid decision-makers in comprehensively exploring the key drivers of solar energy development in Bangladesh in a systematic manner. This aid may have notable implications for the sustainable advancement and implementation of solar energy throughout the country. This study is expected to benefit all policymakers, practitioners, and stakeholders interested in addressing power deficits in developing countries. The study is also expected to have academic implications. Scholars may utilize the propositions and framework developed in this study to conduct both theoretical and empirical assessments of new systems and technologies in countries similar to Bangladesh.

The remainder of this paper is organized as follows. Section 2 conceptualizes the drivers behind solar energy development. Section 3 discusses the methodology, data collection methods, and analysis techniques employed in this research. Section 4 details and discusses our results. Section 5 discusses the managerial and policy implications of the research. Finally, Section 6 concludes the paper.

2. Conceptualizing the drivers of solar energy development in Bangladesh

High dependency on the non-renewable energy sources has become a problem for Bangladesh. Fig. 1 shows different sources of energy consumed by Bangladesh in September 2021. It is evident from the figure that the energy sector of the country largely relies on fossil fuels. Fossil fuel sources like imported petroleum oils and domestic natural gas are most commonly used to satisfy the energy needs of the country.

The Bangladeshi government has also prioritized coal-fired power stations, heavy fuel oil (HFO)-based power plants, and electricity imports from neighboring countries (BPDB, 2021). Fig. 2 shows the fossil fuel consumption in percentage, by the different sectors of Bangladesh. From the chart, it is evident that 'transportation' and 'power generation' are the two biggest consumers of fossil fuel in Bangladesh

Considering such situation, this research attempted to explore ways to promote and develop the clean and reneable energy sources like solar energy in Bangldesh. Several researchers worked in this area in the recent years. For instance, Do et al. (2020) investigated the underlying drivers of Vietnam's solar boom and suggested suitable strategies to boost the adoption of solar energy. Zhang et al. (2011) empirically studied the drivers behind the diffusion of photovoltaic systems in Japan and emphasized the importance of regional diffusion policies and environmental awareness among residents. Kwan (2012) pointed to solar insolation, electricity costs, and financial incentives constitute the most important factors behind the adoption of residential solar photovoltaic systems in the U.S. Ohunakin et al. (2014) identified energy reforms, the urgency of GHG emission reduction, energy security, and employment as the major drivers of solar energy development in Nigeria. Marzia et al. (2018) found that government policies and initiatives, international influences, solar panel price reduction, private sector participation, and public awareness are some of the most important factors behind the development of the Bangladeshi solar energy sector. Importantly, however, Marzia et al. (2018) did not quantitatively assess the drivers' relative influence. Luthra et al. (2016) identified and categorized the key enablers of solar power development in India using a fuzzy decision-making trial and evaluation laboratory (DEMATEL)-based methodology. They also examined the causal relationships among the enablers. Ultimately, they found that entry-level initiatives supported by the central government and subsidy reforms have the most significant positive influence on solar energy development in India. Zhao et al. (2019) explored the interrelationships among the 16 representative factors behind the development of renewable energy projects in China using an ISM-MICMAC approach. They found that incentive policies, government policy implementation, and the economy and urban development constitute the three most important factors. One recent study used a fuzzy BWM technique to investigate barriers to solar energy development in Iran's Alborz Province (Mostafaeipour et al., 2021). Its findings suggest that supporting the private sector with

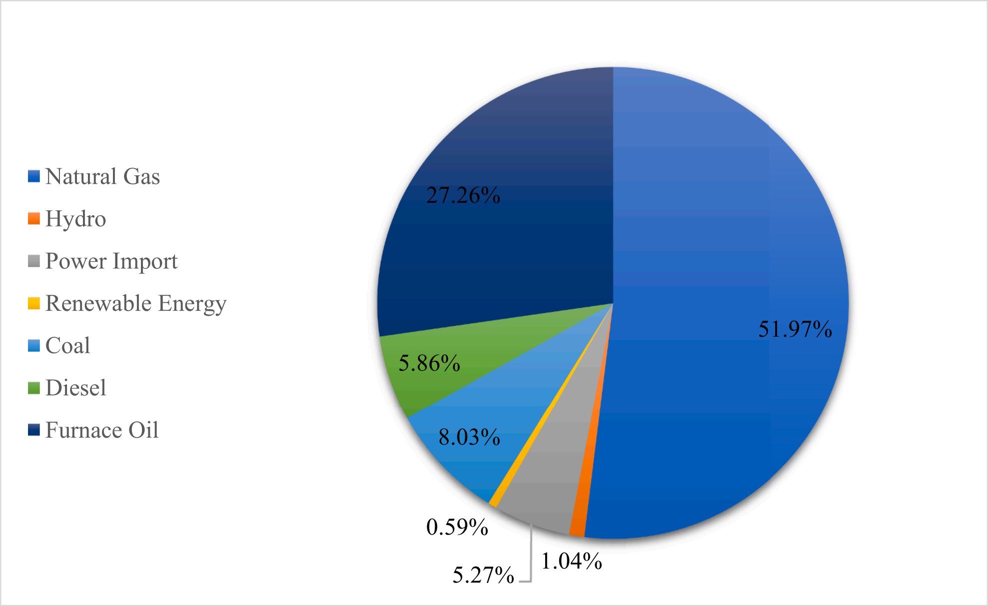

Fig. 1. Energy sources used by Bangladesh on September 2021 (BPDB, 2021).

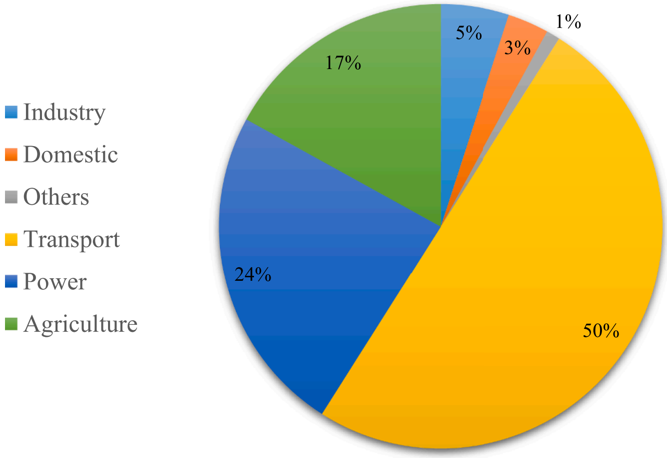

Fig. 2. Fossil fuel consumption by the different sectors of Bangladesh (BPDB, 2021).

financial incentives contributes to the development of the SRE sector. However, there is still no significant research on the identification and prioritization of the drivers of the sustainable solar energy development in the emerging economy perspective, which presents a clear reserch gap. This reaerch, thereby, intends to address this gap.

In this study, through an extensive review of relevant existing research, we identified a total of ten key drivers. We validated these drivers with a team of 21 experts—academics, industrial engineers, and managers working in the SRE field. We communicated with these experts via email. The experts added two additional drivers on top of the ten identified from the literature. The questionnaire used to identify the key drivers is provided in Appendix A of Supplementary Materials. The list of 12 key drivers is presented in Table 1. D5 (large bodies of water) and D12 (Mass awareness) are the drivers that were added by the experts. A brief description of each driver is provided in Appendix B of Supplementary Materials (Table B1).

Table 1
Identified key drivers of solar energy development in Bangladesh.

Code	Driver name	Source
D1	Favorable geographical location in terms of solar irradiation	Mondal and Islam (2011); Podder et al. (2021); Expert feedback
D2	The need to reduce GHG emission	Sharif et al. (2021); Chowdhury (2020); Expert feedback
D3	Support for industrialization	Mekhilef et al. (2011); Chowdhury and Khan (2020); Expert feedback
D4	Govt. policy towards SRE	Liza and Islam (2020); SREDA (2016); Expert feedback
D5	large bodies of water	Expert feedback
D6	Cheaper energy alternative	IRENA (2021); Ishraque et al. (2020); Expert feedback
D7	Peer-to-peer (P2P) energy trading	Kirchhoff and Strunz (2019); Expert feedback
D8	Convenience	Harun (2015); Chakraborty et al. (2016); Expert feedback
D9	Socio-economic development	World Bank (2016); Harun (2015); Expert feedback
D10	Integration opportunity	Mondal and Islam (2011); Expert feedback
D11	Scope for investment and employment	Palit (2013); Expert feedback
D12	Mass awareness	Expert feedback

3. Methodology, data collection, and analysis

The objective of this study is to examine the drivers of solar energy development in Bangladesh. First, we explore the Bangladeshi solar energy sector through a literature review and the opinions of experts (profiles provided in Table 2), identifying a total of 12 drivers. We then rank the identified drivers based on their importance using the BWM.

Table 2
Profiles of the experts.

Experts participated in the identification of the key drivers of sustainable solar energy development in Bangladesh			
Total number of experts (N=21)	Experience	N	Percentage
	< 10 years	11	52.38%
	From 10 to 15 years	6	28.57%
	> 15 years	4	19.04%
Experts participated in scoring the drivers for BWM analysis			
Total number of experts (N=7)	Experience	N	Percentage
	From 10 to 15 years	3	43.85%
	> 15 years	4	57.15%

Next, we employ the ISM method and MICMAC analysis to explore the interactions among these drivers and, in turn, develop an efficient framework that can aid in the formulation of strategies to encourage the sustainable development of Bangladeshi solar energy sector. The design of this study is illustrated in Fig. 3.

3.1. Best-Worst method

Due to the lack of reliable quantitative data on this subject, the only accessible data is input from the experts (Mostafaeipour et al., 2021). Therefore, we have used qualitative data from the experts to achieve the goals of this study. Only a few decision-making methods are suitable for qualitative data, like BWM and AHP. Among those methods, the BWM is the most recent, accurate, and reliable. It reduces the inconsistency ratio and is relatively efficient (Moslem et al., 2020).

The Best-Worst multi-criteria decision-making method was initially formulated by Rezaei (2015). Researchers have since applied it to a wide range of pursuits, including supplier selection, the airline industry, technology assessment, and energy security (Rezaei, 2020). However, this study constitutes the first to use the BWM method to analyze the drivers of sustainable energy development.

Pairwise comparison-based methods like BWM have several advantages over other such methods: (i) As the decision-maker identifies the best and worst criteria prior to comparison, it offers a solid pre-emptive idea regarding the range of evaluation. It results in a more reliable and consistent pairwise comparison; (ii) As it uses two opposite references (best and worst) in a single optimization model, it reduces anchoring bias; (iii) relative to matrix-based methods (like AHP) or single-vector methods (like Swing), BWM is a time- and data-efficient method that requires fewer pairwise comparisons while capable of checking the consistency of the provided pairwise comparisons (Rezaei, 2020). The steps necessary to derive criteria weights using the BWM are described below (Rezaei, 2015).

Step 1: Determine a set of relevant decision criteria using expert opinions. A set of n decision criteria (drivers) is fixed as $\{C_1, C_2, C_3, \ldots. C_n\}$.

Step 2: Identify the best (most important) and worst (least important) criteria from the set identified in Step 1.

Step 3: Determine the preference of the best criterion over the others using a 1–9 scale. Here, 1 implies equal preference, while 9 implies extreme preference. In this way, the best-to-others vector is constructed as follows:

$$A_B = (a_{B1}, a_{B2}, a_{B3}, \ldots\ldots\ldots. a_{Bn}) \tag{1}$$

where a_{Bj} is the preference score of the best criterion B over criterion j.

Step 4: Score the preference of all of the other criteria over the worst using a 1–9 scale. Here, 1 implies equal preference, while 9 implies extreme preference. In this way, the others-to-worst vector is constructed as follows:

$$A_W = (a_{1W}, a_{2W}, a_{3W}, \ldots\ldots\ldots a_{nW}) \tag{2}$$

where a_{jW} is the preference score of criterion j over the worst criterion W.

Step 5: Calculate the optimal weights of the criteria (W_1^*, W_2^*, W_3^*, ...W_n^*). In this step, optimized criteria weightings are determined where the maximum absolute difference $|\frac{w_B}{w_j} - a_{Bj}|$ and $|\frac{w_j}{w_w} - a_{\mathrm{jw}}|$ for all values of j is minimized. The problem can be written as:

$$\min_j \max \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{\mathrm{jW}} \right| \right\}$$

subject to,

$$\sum_j w_j = 1$$

$$W_j \geq 0 \tag{3}$$

for all j

Problem (3) can be converted to a linear programming problem as follows:

$$\min \xi^L$$

subject to,

$$|w_B/w_j - a_{Bj}|\xi^L$$

for all j

$$|w_j/w_W - a_j W| \leq \xi^L$$

for all j

$$W_j \geq 0 \tag{4}$$

for all j

By solving model (4), we achieve the optimal weights (W_1^*, W_2^*, W_3^*, ...W_n^*) and the minimized value of ξ^{L^*}. The lower the ξ^{L^*}, the higher the consistency of the results, and the more reliable the comparisons become.

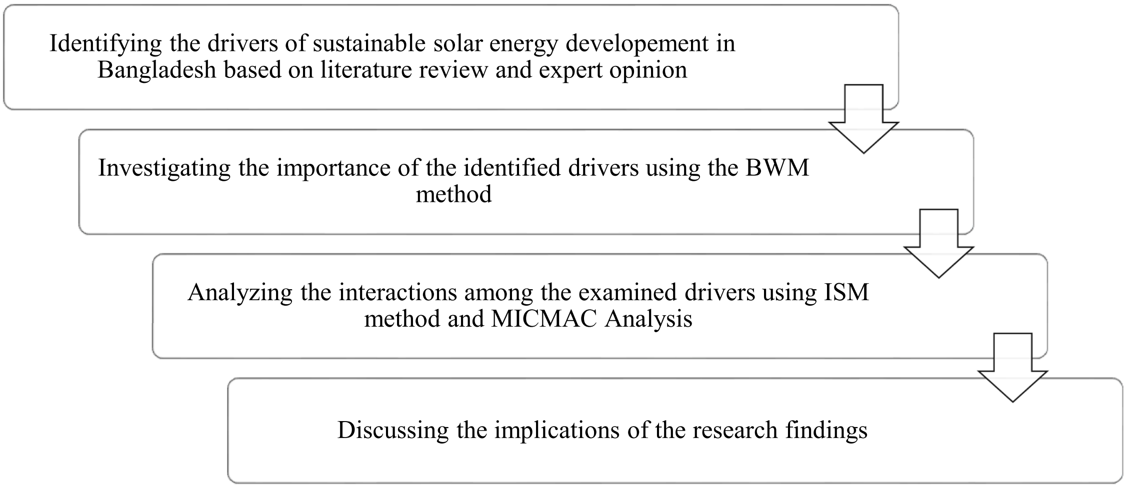

Fig. 3. Study design.

3.2. *Interpretive structural modeling*

The interpretive structural modelling (ISM) technique is an interactive methodology that structures the multifaceted elements of an issue into a robust systematic model to map out the complex relationships among its variables (Warfield, 1974). As such, it can be used to gain insight into any issue in a structured and efficient manner (Ravi & Shankar, 2005). ISM is suitable for application across many fields, including supply chain management (Menon & Ravi, 2021), reverse logistics (Ravi & Shankar, 2005), supplier selection (Beikkhakhian et al., 2015), green lean implementation (Cherrafi et al., 2017), shipping policy (Song et al., 2019), and sustainable business (Abuzeinab et al., 2017). The stepwise procedure of the ISM approach undertaken in this research is detailed in ***Appendix C*** of ***Supplementary Materials*** (Modified from Ansari et al., 2013; Gopal & Thakkar, 2016; Attri & Grover, 2018). The flow chart illustrating the ISM hierarchical model of the drivers behind solar energy development in Bangladesh is provided in Figure 4.

3.2.1. *MICMAC analysis*

MICMAC analysis has been performed to assess factors' driving power and dependence power. This type of analysis is rooted in the multiplication properties of the matrices (Sharma et al., 1995). Based on factors' driving power and dependence power, it classifies them into four categories (Attri et al., 2013). First, "autonomous factors" are drivers with weak driving power and weak dependence power. Although they are relatively disconnected from the system, the existing links may be very strong. Second, "linkage factors" are drivers with strong driving power and strong dependence power. These factors are unstable and any change to these drivers affects other drivers and has a feedback effect on them. Third, "dependent factors" are mainly dependent on other factors. These drivers have weak driving power but strong dependence power. Fourth, "independent factors" are drivers with strong driving power but weak dependence power.

3.3. *Data collection and analysis*

Now, we send the key drivers identified in Section 2 to seven experts experienced in the Bangladeshi solar energy sector, either as academics or practitioners. The experts' profiles are provided in Table 2 below. We send the experts a set of questionnaires based on the BWM via email (Google Forms). The questionnaire is provided in ***Appendix D*** of ***Supplementary Materials***.

The experts identify the best and worst drivers—the most important

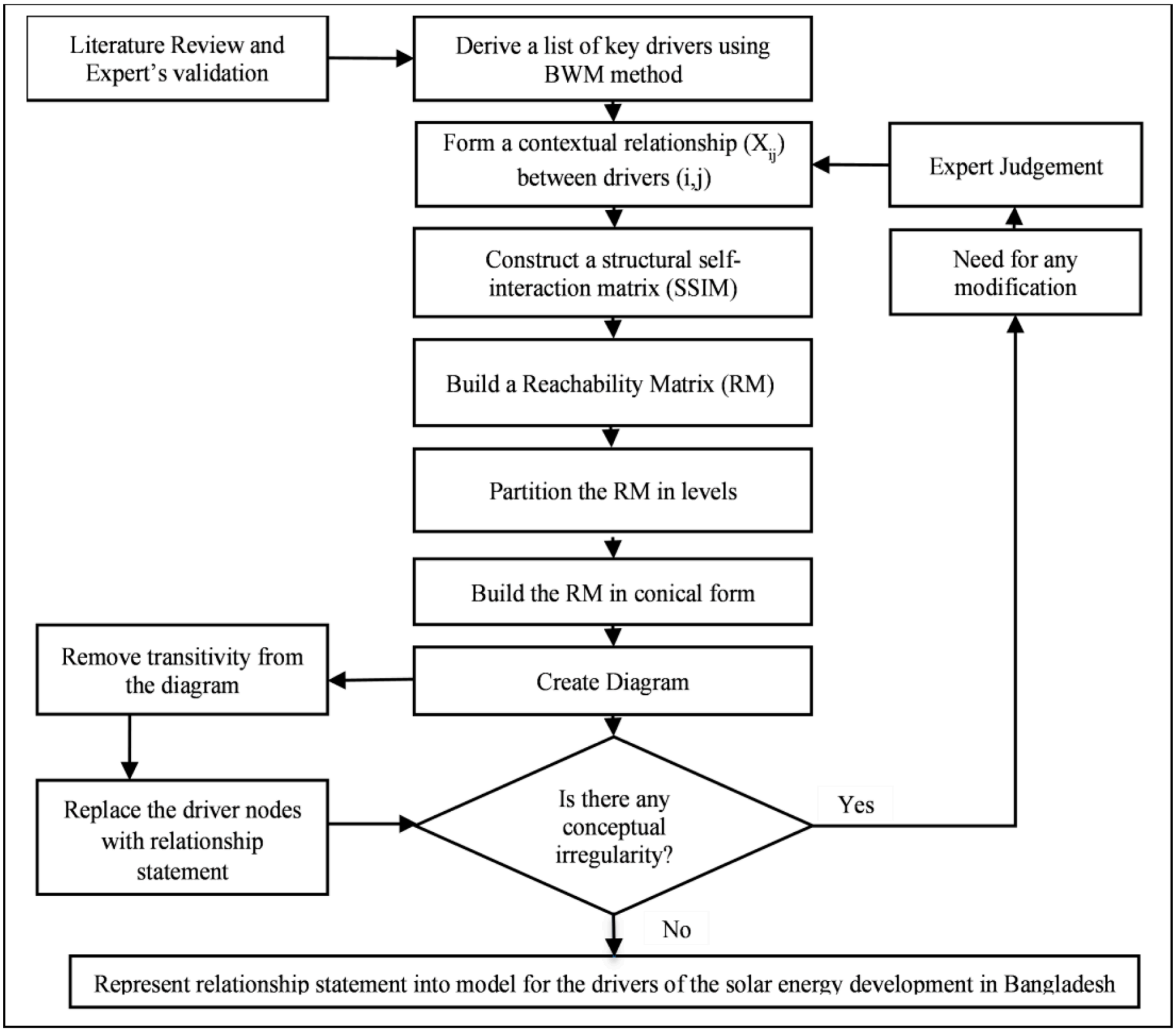

Fig. 4. Flow chart of the ISM hierarchical model (Modified from Moktadir et al., 2017; Luthra et al., 2011).

and least important—behind the solar energy sector in Bangladesh. They then conduct a pairwise comparison to score the drivers using Eqs. (1) and (2). Using the model (4), each respondent calculates the optimal weights of the 12 criteria.

Through the stepwise procedure of Section 3.1 and model (4), we construct Table E1 and Table E2, which are provided in Appendix E of Supplementary Materials. Since our questionnaires are based on the AHP method, examining the consistency ratio of the experts' responses reveals the reliability and suitability of the comparisons. We check the consistency ratio of the pairwise comparisons based on the input thresholds from Liang et al. (2020) and find that all of the pairwise comparisons are reliable. The final rankings of the drivers are reached by averaging the weights from each expert through the BWM. They are presented in Table 3.

Of the 12 drivers ranked in this section, we explore the interrelationships among the nine most important ones via the ISM-MICMAC method, which is presented in the following two subsections.

3.3.1. *Construction of ISM-based hierarchical model*

In this phase, with the input of an expert with 25 years of both academic and practical experience in the Bangladeshi solar energy sector, we develop a Structural Self-Interaction Matrix (SSIM) using the nine most important drivers obtained from the previous section. Table 4 shows the SSIM with these drivers.

We develop the initial reachability matrix, shown in Table 5, by replacing the SSIM symbols with 1s and 0s, following Table C1 in ***Appendix C***.

Next, we incorporate transitivity to produce the final reachability matrix, which is shown in Table 6. The values marked with * display the transitivity.

Using Table 6, we calculate the dependence power and driving power of each driver. We then use these values to classify the drivers through MICMAC analysis, which we detail in the following subsection.

Next, we conduct the level positioning from the final reachability matrix by following Step 5 of ***Appendix C***. For this purpose, we use the matrix to determine the reachability, antecedent, and interaction set of each driver. The iterations of initial level partitioning are shown in Tables F1–F5 in ***Appendix F*** of ***Supplementary Materials***. The final level partitioning after five iterations is shown in Table 7.

The obtained levels enable us to develop the final ISM graphical structure. This structure is depicted in Fig. 5, which illustrates the interrelationships among the drivers as well as their positions in the hierarchical structure.

3.3.2. *Driver classification through MICMAC analysis*

In addition to placing the drivers in a hierarchal structure via the ISM-based model, we classify them based on their level of influence through the MICMAC approach. To do this, we plot the driving power and dependence power of each driver (shown in Table 6) in a MICMAC graph (shown in Fig. 6).

Table 3
Average weights and ranks of the drivers obtained through the BWM.

Drivers of solar energy development in Bangladesh	Average weight	Rank
Favorable geographical location in terms of solar irradiation (D1)	0.1939	1
The need to reduce greenhouse gas emission (D2)	0.1364	3
Support for industrialization (D3)	0.0699	5
Govt. policy towards SRE (D4)	0.1413	2
Large bodies of water (D5)	0.0626	6
Cheaper energy alternative (D6)	0.0619	7
Peer-to-peer (P2P) energy trading (D7)	0.0373	12
Convenience (D8)	0.0507	9
Socio-economic development (D9)	0.0551	8
Integration opportunity (D10)	0.0410	11
Scope for investment and employment (D11)	0.1031	4
Mass awareness (D12)	0.0468	10

Table 4
Structural Self-Interaction Matrix (SSIM).

Drivers	D11	D9	D8	D6	D5	D4	D3	D2	D1
D1	V	V	V	O	O	V	O	O	X
D2	V	V	O	V	O	V	V	X	
D3	X	V	O	V	A	A	X		
D4	V	V	V	V	A	X			
D5	V	V	V	V	X				
D6	O	V	V	X					
D8	A	O	X						
D9	A	X							
D11	X								

Table 5
Initial reachability matrix of the drivers.

Drivers	D1	D2	D3	D4	D5	D6	D8	D9	D11
D1	1	0	0	1	0	0	1	1	1
D2	0	1	1	1	0	1	0	1	1
D3	0	0	1	0	0	1	0	1	1
D4	0	0	1	1	0	1	1	1	1
D5	0	0	1	1	1	1	1	1	1
D6	0	0	0	0	0	1	1	1	0
D8	0	0	0	0	0	0	1	0	0
D9	0	0	0	0	0	0	0	1	0
D11	0	0	1	0	0	0	1	1	1

In MICMAC analysis, "favorable geographical location in terms of solar irradiation" (D1), "government policy toward sustainable renewable energy" (D4), "the need to reduce greenhouse gas emissions" (D2), and "large bodies of water" (D5) are "independent" drivers, as they have high driving power but low dependence power. They constitute the most significant drivers behind the sustainable development of solar energy in Bangladesh. "Cheaper energy alternative" (D6), "convenience" (D8), and "socio-economic development" (D9) are "dependent" drivers, as they have weak driving power but strong dependence power. "Support for industrialization" (D3) and "scope for investment and employment" (D11) are "linkage" drivers between independent and dependent variables. No driver is identified as "autonomous." Evidently, all nine of the drivers used in the ISM-MICMAC approach are significant and relevant to the sustainable development of solar energy in Bangladesh.

4. Results and discussion

By implementing the BWM in Section 3.3, this study has found that 'Favourable geographical location in terms of solar irradiation' has the highest weight and is, therefore, ranked first among the drivers of solar energy development in Bangladesh. 'Govt. policy towards SRE' and 'the need to reduce GHG emission' are the second and third most important drivers, respectively. On the other end, 'mass awareness', 'integration opportunity' and 'peer-to-peer (P2P) energy trading' are the tenth, eleventh, and twelfth most important drivers, respectively. Of course, we only used the top nine drivers from the BWM to develop the ISM-based hierarchical structure.

For the ISM analysis, we partitioned the levels in line with the driving power and dependence power of the drivers. The five resultant levels are shown in Table 7 and Fig. 3. 'Favorable geographical location in terms of solar irradiation', 'the need to reduce GHG emission' and 'large bodies of water' are positioned at the bottom (fifth) level, while 'convenience' and 'socio-economic development' are positioned at the top (first) level. These findings indicate that vast bodies of water, a geographical location with high solar irradiation, and an urgent need to reduce GHG emission may act as significant drivers of the other drivers, while convenience and socio-economic development are likely achieved simultaneously. Setting up solar cells in the water bodies also conserves usable land spaces, which is quite important, specially for a densely

Table 6
Final reachability matrix of the drivers.

Drivers	D1	D2	D3	D4	D5	D6	D8	D9	D11	Driving Power
D1	1	0	1*	1	0	1*	1	1	1	7
D2	0	1	1	1	0	1	1*	1	1	7
D3	0	0	1	0	0	1	1*	1	1	5
D4	0	0	1	1	0	1	1	1	1	6
D5	0	0	1	1	1	1	1	1	1	7
D6	0	0	0	0	0	1	1	1	0	3
D8	0	0	0	0	0	0	1	0	0	1
D9	0	0	0	0	0	0	0	1	0	1
D11	0	0	1	0	0	1*	1	1	1	5
Dependence Power	1	1	6	4	1	7	8	8	6	

Table 7
Final level partitioning of the final reachability matrix.

Drivers	Reachability set	Antecedent set	Intersection set	Level
D1	D1,D3,D4,D6,D8, D9,D11	D1	D1	V
D2	D2,D3,D4,D6,D8, D9,D11	D2	D2	V
D3	D3,D6,D8,D9,D11	D1,D2,D3,D4,D5,D11	D3,D11	III
D4	D3,D4,D6,D8,D9, D11	D1,D2,D4,D5	D4	IV
D5	D3,D4,D5,D6,D8, D9,D11	D5	D5	V
D6	D6,D8,D9	D1,D2,D3,D4,D5,D6, D11	D6	II
D8	D8	D1,D2,D3,D4,D5,D6, D8,D11	D8	I
D9	D9	D1,D2,D3,D4,D5,D6, D9,D11	D9	I
D11	D3,D6,D8,D9,D11	D1,D2,D3,D4,D5,D11	D3,D11	III

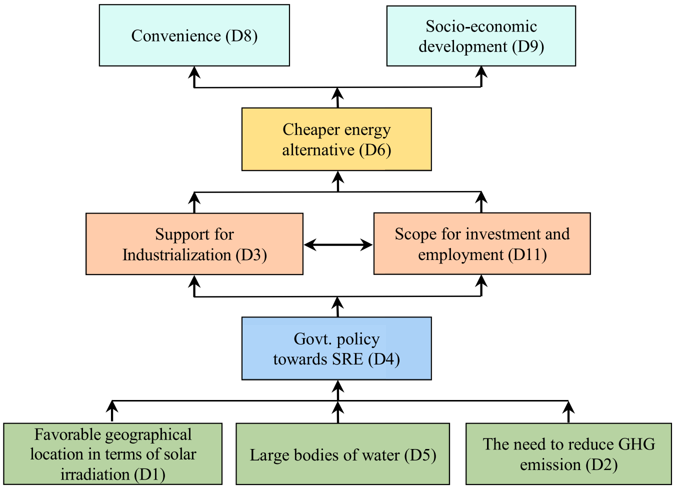

Fig. 5. ISM model of the drivers.

populated country like Bangladesh, where land is both expensive and scarce. Utilizing water bodies for harnessing solar energy will free up the lands to used for other important environmental and economic purposes. Activities like forestation, tourism etc. are not usually hampered by such installations either, which is also an important benefit of setting up FSPVs in water bodies. The remaining four drivers, 'govt. policy towards SRE', 'support for industrialization', 'scope for investment and employment', and 'cheaper energy alternative' lie somewhere between the top and bottom levels. Again, it must be noted that driving power decreases and dependence power increases from the bottom to the top of the hierarchical model, indicating that lower-level drivers may aid in attaining and amplifying the drivers above them.

In the ISM results, it is interesting to note that 'favourable geographical location in terms of solar irradiation', which has received the highest weight in the BWM analysis, has also received the highest driving power and the lowest dependence power; thus, it is positioned at the bottom (fifth) level of the ISM model. Similarly, 'convenience', which holds the lowest (ninth) rank among the top nine drivers in the BWM analysis, has the lowest driving power and the highest dependence power, resulting in its position at the top (first) level of the ISM model.

We used the MICMAC approach to justify our ISM-based model by categorizing the drivers into four clusters: independent, dependent, linkage, and autonomous. We determined 'Favorable geographical location in terms of solar irradiation', 'the need to reduce GHG emission', 'govt. policy towards SRE' and 'large bodies of water' to be independent drivers, as they have strong driving power but weak dependence power, and 'cheaper energy alternative', 'convenience' and 'socio-economic development' to be dependent drivers, as they have weak driving power but strong dependence power. This indicates that these drivers are highly dependent on the other identified drivers. We identified 'support for industrialization' and 'scope for investment and employment' as linkage drivers, meaning they function as links between independent and dependent variables. Hence, these drivers lie in the middle of the hierarchical model. We found none of the drivers to be autonomous, suggesting that all of them are important to foster the sustainable growth of solar energy in Bangladesh.

In our ISM-based analysis, we identified 'favorable geographical location in terms of solar irradiation', 'large bodies of water' and 'the need to reduce GHG emission' as having the highest driving power (and lowest dependence power). Bangladesh receives a solid amount of year-round solar irradiation. It is home to massive coastal areas, rivers, lakes, and reservoirs, meaning it holds enormous FSPV potential. Bangladesh needs to take steps to increase the share of renewable energy in the national energy mix as part of its commitments to the Paris Climate Agreement, COP26 and the SDGs. These three drivers ('favorable geographical location in terms of solar irradiation', 'large bodies of water' and 'the need to reduce GHG emission') will prompt the country to adopt policies that are more favorable to the implementation of sustainable solar energy initiatives by expanding the scope of investment, manufacturing, and employment.

The findings obtained from this study offer interesting insights. Several previous studies have noted that Bangladesh's tropical location has a strong potential for harnessing solar energy (Khan et al., 2018; Podder et al., 2021). Thereby, 'favorable geographical location in terms of solar irradiation' receiving the highest weight in the BWM ranking and the highest driving power in the ISM hierarchy is quite justifiable. Again, BWM ranked integration opportunity and peer-to-peer energy trading in the second-to-last and last positions, respectively. These unique findings obtained from this study are expected to offer new perspectives on the drivers of sustainable Solar Energy Development in Bangladesh, both to the decision makers and the future researchers in this area.

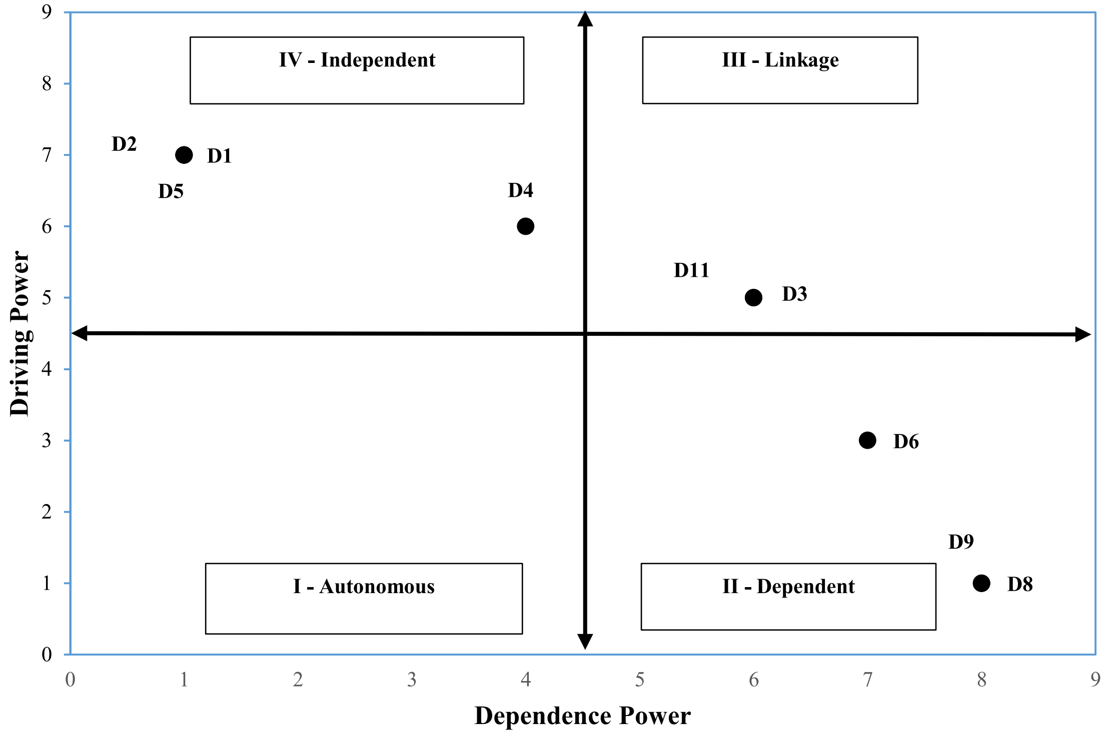

Fig. 6. MICMAC driver analysis.

According to Chowdhury (2020), grid integration has enormous potential, though on-grid households and industrial users have yet to reap its full advantages. In the least developed countries, traditional power structures are centralized and follow a top-down hierarchy. Bangladesh's prosumerism model is based on a bottom-up approach, allowing greater flexibility in terms of sustainability and easier integration of the energy prosumers. It will aid in the electrification of rural areas without requiring huge investments (Kirchhoff and Strunz, 2019). According to Khan (2019a), despite some success in the pilot prosumerism projects in off-grid direct-current networks, conflicts of interest remain between distributed nano-grid and utility-grid sectors. The shortage of appropriate technology for the integration of direct-current networks to the grid is another existing barrier to their expansion. Nevertheless, peer-to-peer energy trading has immense possibility to drive the energy sector sustainably from the perspective of Bangladesh. Favorable government policies, tax break, tax credit and other economic incentive can further encourage general population to participate in peer-to-peer energy trading. Launching a mass awareness campaigns on the benefits of peer-to-peer energy trading can also help in this regard.

It is worth discussing how we identified the "large bodies of water" driver as one with high driving power and placed it at the bottom (fifth) level of ISM structure despite, in the BWM ranking, it receives the sixth position with a low weight (0.0656). This scenario can be explained by the fact that a large-scale FSPV project currently operating in the Kaptai river of Bangladesh has already made a noteworthy contribution to the national grid. Thereby, taking this success as an example, more such FSPVs should be installed on the many other existing waterbodies of the country, so that together they can have a significant contribution to the overall development of the country's solar power sector. This technology has outstanding potential—especially in the context of a densely populated country like Bangladesh, where the amount of unused land area is not abundant (Chowdhury et al., 2020; Miah et al., 2021).

The results of the study contrast to a significant extant with other relevant studies, where the drivers are explored based on other countries or used other methodologies. For instance, Marzia et al. (2018) discussed the most significant drivers behind Bangladesh's solar power development. However, they did not evaluate the drivers' relative influence quantitatively, nor did they explore the interrelations among the drivers. Luthra et al. (2016) analyzed the key enablers of solar power development in the context of India using fuzzy DEMATEL approach and observed that state level government initiatives, redesigning power sector policy and foreign direct investment (FDI) have the highest influence on India's solar energy sector development. In contrast, this study has found that favorable geographical location in terms of solar irradiation, government policy towards SRE and the need to reduce GHG emission are the top most important drivers for Bangladesh's solar power development. Again, this study uniquely found that large water bodies with a potential for installment of FSPV plants, the emergence of peer-to-peer energy trading in the large existing SHS network, and mass awareness are unique drivers identified for the solar energy development in the context of Bangladesh. In a recent study, Mostafaeipour et al. (2021) explored the barriers of solar energy development in Iran's Alborz Province using fuzzy BWM method. However, they did not explore the drivers.

Thereby, this study of relative importance and interrelations among the drivers promoting the sustainable solar energy development in Bangladesh can offer unique perspective and useful implications to the other emerging economies. This research demonstrates and highlights various potential areas for the development of sustainable solar energy in Bangladesh and the findings from this research are expected to encourage government, policy makers and other stakeholders to make decision and and implement policies that will help to reduce the nation's dependency on fossil fuels and expansion of solar energy technology to a greater extent. This will not only allow the country to keep its pledge taken in the Paris Climate Agreement and in COP26, but also contribute to the reduction of the global GHG emission.

5. Managerial and policy implications

This research has several important implications. Based on the findings of this research, action plans may be devised to boost the sustainability of the solar energy sector in Bangladesh. For instance, behavioural change among prosumers regarding energy usage could encourage the integration of the prosumer-based direct-current nanogrid system with the utility grid, making peer-to-peer energy-sharing practices more efficient. A vigorous campaign and awareness program on the comparative advantages of solar energy could be highly effective in this regard. This can help to boost the number of consumers and can also contribute to modifying or changing consumer and prosumer behavior, which is necessary for the mass expansion of this sector. . Focusing on issues like installing utility-scale solar PV plants and peer-to-peer energy trading, like in the neighbouring countries of India and China, can also boost overall development. Government can offer consumer level tax credit to encourage the usage of utility-scale solar PV plants and peer-to-peer energy trading. Reducing the import tax on solar PV parts can also help in this regard.

The findings from this study also suggest that focusing on independent drivers like ‘implementing policies aimed at boosting renewable energy’ and ‘expanding FSPVs on large bodies of water’—could significantly boost overall development. Bangladesh is geographically blessed both due to being in a location that receives a very high solar irradiance and due to the presence of a lot of water bodies throughout the country. If these benefits can be properly utilized, the country will be able to harness a lot of solar energy by spending a lot less money. For instance, by setting up a large number of floating PV cells, the country can utilize its large water bodies without wasting much land space. Unutilized spaces like residential and commercial rooftops can also be utilized by setting up utility grade solar PVs and connecting them in peer-to-peer energy sharing network to reduce the waste of the unutilized energy.

Revision of the government policies can also help in this regard. Government agencies can review existing energy policies to eliminate those that inappropriately favour fossil fuels and non-renewable technologies over SRE sources, making solar power a more price-competitive option. Crucially, a proper understanding of the relevant drivers behind the development of solar energy can aid energy investors and policymakers in making appropriate decisions, attracting better investments, and developing more targeted policy frameworks to improve sustainability.

6. Conclusions

Solar energy holds immense potential for Bangladesh to capitalize on its current economic upturn while sustainably improving energy access, livelihoods, and access to better healthcare services for its population. Bangladesh faces a sharp increase in energy demand due to its rapid population and economic growth. The need to address this rising demand while minimizing negative externalities has led to the development of the solar energy sector. This study is the first to evaluate the main drivers behind the sustainable development of the Bangladeshi solar energy sector.

This research demonstrated that the drivers of solar energy development do not always work independently or discretely. One driver can have significant impacts on other drivers. Thus, the hierarchical structure developed in this paper will provide policymakers with a comprehensive understanding of the various drivers’ influence on the diffusion of solar energy technology throughout Bangladesh. This knowledge will assist managers and decision-makers in improving the efficiency of the country’s solar energy sector, leading to enhanced long-term outcomes.

However, this research has some limitations as well. For instance, the research was performed based on the subjective judgments of academic and industrial experts working in the Bangladeshi solar energy sector, specially for the BWM and ISM techniques. Hence, there is always some chance of subjective bias in the obtained results. This study focused on just 12 key drivers—an unexhaustive list. Thereby, more relevant drivers can be searched and added in the future. Finally, the overall status of solar energy in Bangladesh is constantly changing, meaning that this study’s findings may become outdated over the next 5 to 10 years.

In the future, researchers could combine fuzzy sets with this study’s BWM-ISM hybrid method to optimize the potential uncertainty and ambiguity in the crisp value inputs from the expert feedback. Researchers can also apply other MCDM tools to analyze the same problem in order to conduct comparative analysis among the results obtained from different methods. Finally, future researchers can utilize the integrated BWM and ISM-MICMAC hybrid tool used in this study to explore the solar energy sector or other relevant energy sectors in other countries as well.

Credit authorship statement

Md. Zahidul Anam: Conceptualization, Visualization, Data Curation, Formal analysis, Methodology, Resources, Investigation, Writing - Original Draft.**A. B. M. Mainul Bari:** Conceptualization, Methodology, **Supervision**, Project administration, Resources, Software, Writing-reviewing & editing, Validation.**Sanjoy K Paul** – Writing-reviewing & editing, Investigation, Validation.**Syed Mithun Ali:** Writing - Reviewing & Editing, Investigation, Validation.**Golam Kabir:** Writing - Reviewing & Editing, Resources, Validation

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rcradv.2022.200068.

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