EXPLORATION OF THE DRIVERS OF SOLAR ENERGY DEVELOPMENT IN BANGLADESH: A MUTICRITERIA DECISION MAKING APPROACH

By

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CERTIFICATE OF APPROVAL

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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. This is done by adopting an integrated methodology. First, through a literature review and expert feedback, 12 drivers of solar energy development are identified. This study then employs the best-worst method (BWM) to rank the drivers based on their significance and uses the Interpretive Structural Modeling (ISM) along with Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) methodology to analyze the interrelationships among them. The findings indicate that favorable 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 contributes to the literature on sustainable solar energy development in a systematic way that benefits both decision-makers and end-users.

Table of Contents

List of Figures

List of Tables

CHAPTER 1

INTRODUCTION

1.1. Background of the Study

Bangladesh hosts one of the world's most rapidly growing economies. The country aspires to be a high-income country by 2041 and this economic expansion largely relies on the 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 the 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).

Currently, the Bangladeshi energy sector relies on fossil fuels—mainly imported petroleum oils and domestic natural gas—to address its energy needs. The Bangladeshi government has prioritized coal-fired power stations, nuclear power plants, and electricity imports from neighboring countries. 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 and Herndon, 2018; Zierold and Odoh, 2020). Nuclear power plants also carry with them serious safety, health, and stability risks (Hirose, 2012; Yoshida and 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 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 severe fiscal 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 Liquefied Natural Gas (LNG) with high tariffs and subsidies.

In 2019, global GHG emissions increased for the third consecutive year, hitting a new record of 59.1 $GtCO_2e$ (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. However, there are currently only three Bangladeshi policies related to the promotion of solar energy—"Renewable Energy Policy 2008," "Solar Energy Development Guideline 2013," and "Net Metering Policy 2018"—all of which are still in the guideline phase and have yet to achieve any visible long-term outcomes. Additionally, financial issues, a lack of resource data, a lack of expertise, and inadequate research activities continue to limit the implementation of solar energy in Bangladesh (Podder et al., 2021).

In order to successfully promote the integration of SRE sources like solar energy in the national grid, it is necessary to 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. Hence, this study aims to address this gap in the literature from a decision analysis perspective.

1.2 Objectives of the Study

The specific objectives of this study are:

- To identify the key factors that can drive the growth of solar energy in Bangladesh.
- To evaluate the weights of the identified factors and then rank them to have an insight on the intensity and priority of each of the factors for solar energy development. BWM method has been used for this purpose
- To explore the contextual relationships among the drivers using ISM-MICMAC approach.

1.3 Contributions of the study

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.

This thesis has been organized into five chapters, along with the list of references that and appendices. Chapter 1 "Introduction" contains the background, objectives, and contributions of the present study. Chapter 2 conceptualizes the drivers of solar energy development in Bangladesh. Chapter 3 deals with the methodology, data collection, and analysis of the study. Chapter 4 consists of results and discussion on the results. Finally, Chapter 5 contains the conclusion and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Review on the Drivers of Solar Energy

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.

2.2 Review on MCDM Techniques

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 financial incentives contributes to the development of the SRE sector.

2.3 Conceptualizing the Drivers of Solar Energy Development in Bangladesh

This study, through an extensive review of relevant existing research, identifies a total of ten key drivers. These drivers are validated with a team of 21 experts—academics, industrial engineers, and managers working in the SRE field. This communication with the expert is done via email. Two additional drivers are found from their feedback. These two are added to the ten identified from the literature. The questionnaire used to identify the key drivers is provided in Appendix A. The list of 12 key drivers is presented in Table 1. D5 and D12 are the drivers that were added by the experts. A brief description of each driver is provided in Appendix B (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

CHAPTER 3

METHODOLOGY, DATA COLLECTION, AND ANALYSIS

The objective of this study is to examine the drivers of solar energy development in Bangladesh. First, this study explores 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. Then the identified drivers are ranked based on their importance using the BWM. Next, ISM method and MICMAC analysis are employed 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 the Bangladeshi solar energy sector. The design of this study is illustrated in Figure 1.

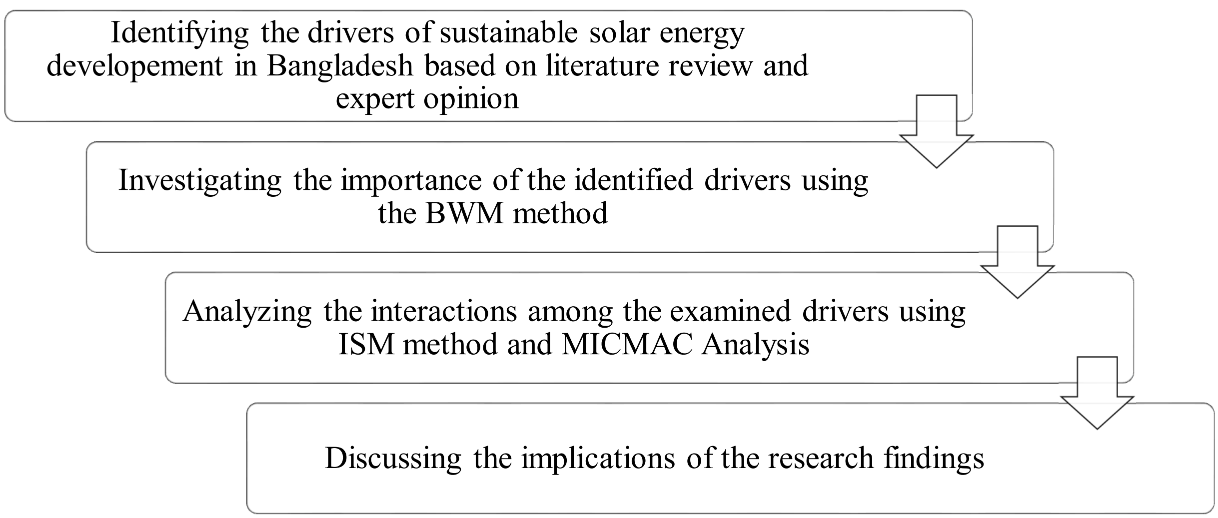

Figure 1. Study design

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, qualitative data from the experts is used to achieve the goals of this study. Few decision-making methods are suitable for qualitative data.

Among those that use qualitative data, 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: (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 $\{C_1, C_2, C_3, \dots. C_n\}$.

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:

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

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:

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

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

Step 5: Calculate the optimal weights of the criteria ($w_1^*, w_2^*, w_3^*, \ldots\ldots\ldots\ldots w_n^*$). In this step, optimized criteria weightings are determined where the maximum absolute difference $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_w} - a_{\mathrm{jw}}\right|$ for all values of *j* is minimized. The problem can be written as:

$$\min \max_J \left\{ \left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{\mathrm{jw}}\right| \right\}$$

subject to,

$$\sum_j w_j = 1$$

$w_j \geq 0$, for all j (3)

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

$\min \xi^L$

subject to,

$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi^L$, for all j

$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi^L$, for all j

$w_j \geq 0$, for all j (4)

By solving model (4), the optimal weights (w_1^*, w_2^*, w_3^*, ……………. w_n^*) and the minimized value of ξ^{L^*} are achieved. The lower the ξ^{L^*}, the higher the consistency of the results, and the more reliable the comparisons become.

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 and Shankar, 2005). ISM is suitable for application across many fields, including supply chain management (Menon and Ravi, 2021), reverse logistics (Ravi and 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 (Ansari et al., 2013; Gopal and Thakkar, 2016; Attri and Grover, 2018).

The flow chart illustrating the ISM hierarchical model of the drivers behind solar energy development in Bangladesh is provided in Figure 2.

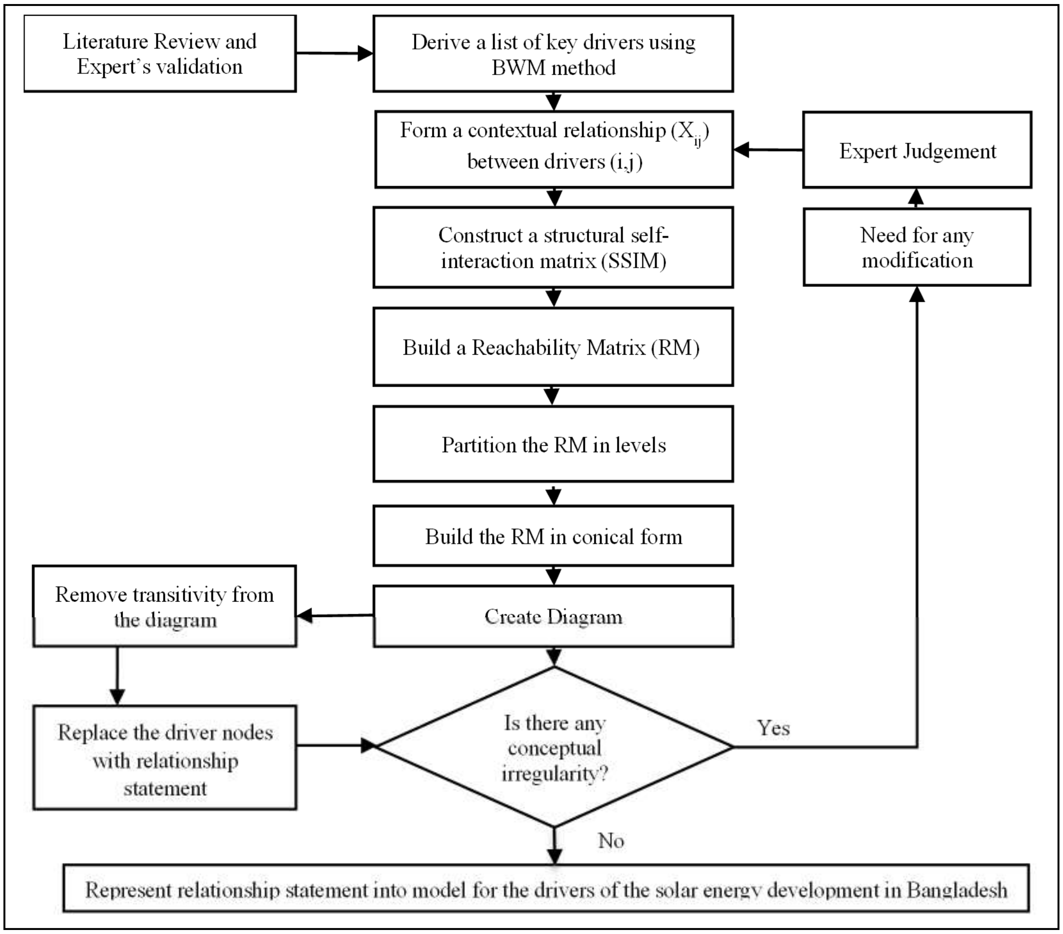

Figure 2. Flow chart of the ISM hierarchical model (Modified from Moktadir et al., 2017; Luthra et al., 2011).

3.2.1 MICMAC analysis

MICMAC analysis serves 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 themselves. 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, the key drivers identified in Section 2 are sent to seven experts experienced in the Bangladeshi solar energy sector, either as academics or practitioners. The experts' profiles are provided in Table 2 below. A set of questionnaires is sent to the experts based on the BWM via email (Google Forms). The questionnaire is provided in Appendix D.

Table 2. Expert 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%

The experts identify the best and worst drivers—the most important 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 model (4), each respondent calculates the optimal weights of the 12 criteria.

Through the stepwise procedure of Section 3.1 and model (4), Table E1 and Table E2 are constructed, which are provided in Appendix E. Since the questionnaires are based on the AHP method, examining the consistency ratio of the experts' responses reveals the reliability and suitability of the comparisons. The consistency ratio of the pairwise comparisons is checked based on the input thresholds from Liang et al. (2020) and all of the pairwise comparisons are found 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.

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

Of the 12 drivers ranked in this section, the interrelationships among the nine most important ones are explored via the ISM-MICMAC method. It is presented in the following two subsections (3.3.1 and 3.3.2).

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, this study develops 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.

Table 4. Structural self-interaction matrix

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								

This study develops the initial reachability matrix, shown in Table 5, by replacing the SSIM symbols with 1s and 0s, following Table C1 in Appendix C.

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

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

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	

Using Table 6, the dependence power and driving power of each driver are calculated. These values are then used to classify the drivers through MICMAC analysis, which is detailed in the following subsection.

Next, the level positioning is conducted from the final reachability matrix by following Step 5 of Appendix C. For this purpose, the matrix is used 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. The final level partitioning after five iterations is shown in Table 7.

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

The obtained levels enable this study to develop the final ISM graphical structure. This structure is depicted in Figure 3, which illustrates the interrelationships among the drivers as well as their positions in the hierarchical structure.

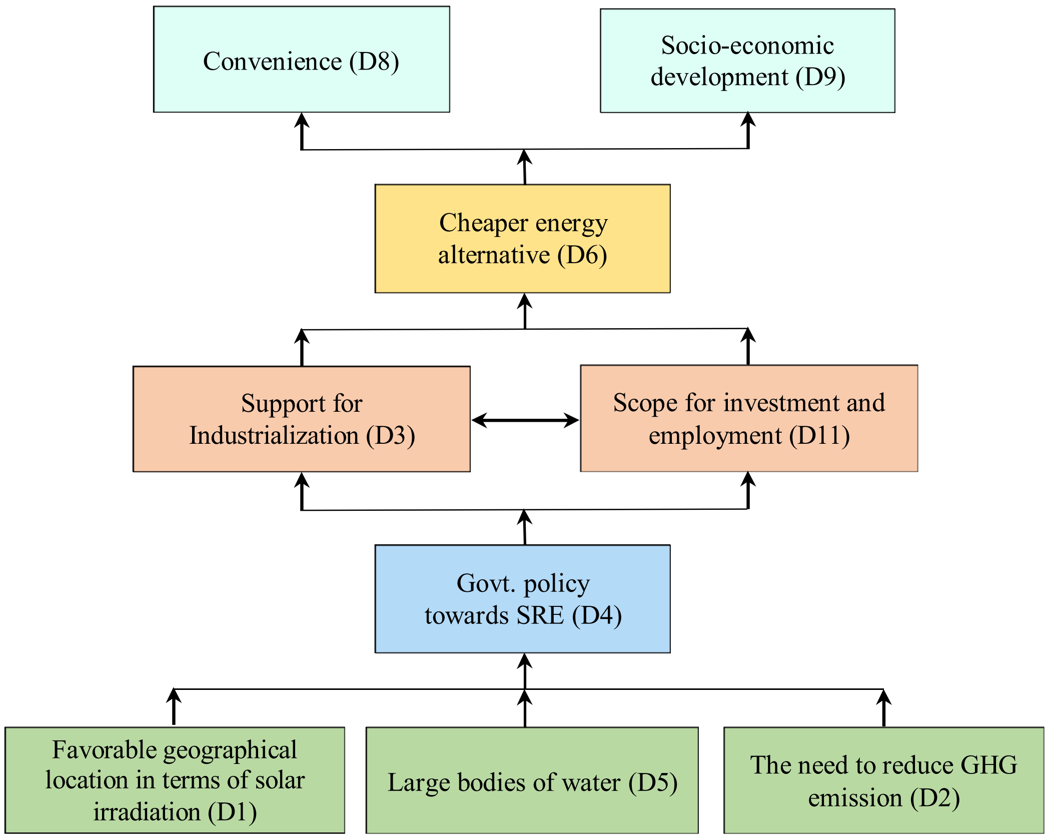

Figure 3. ISM model of the drivers

3.3.2 Driver classification through MICMAC analysis

In addition to placing the drivers in a hierarchal structure via the ISM-based model, this study classifies them based on their level of influence through the MICMAC approach. To do this, the driving power and dependence power of each driver (shown in Table 6) are plotted in an MICMAC graph (shown in Figure 4).

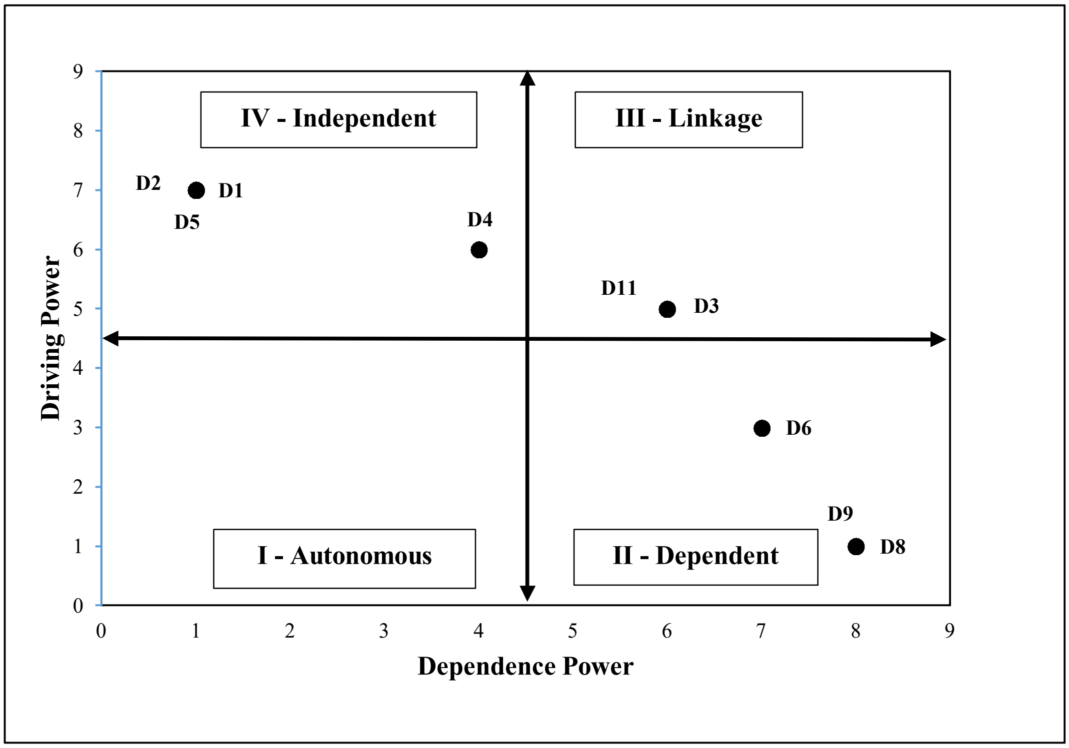

Figure 4. MICMAC driver analysis

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.

CHAPTER 4

RESULTS, DISCUSSION AND IMPLICATIONS

4.1 Results

By implementing the BWM in Section 3.3, this study has found that D1 has the highest weight and is, therefore, ranked first among the drivers of solar energy development in Bangladesh. D4 and D2 are the second and third most important drivers, respectively. On the other end, D12, D10, and D7 are the tenth, eleventh, and twelfth most important drivers, respectively. Of course, this study only used the top nine drivers from the BWM to develop the ISM-based hierarchical structure.

For the ISM analysis, level partitioning is done in line with the driving power and dependence power of the drivers. The five resultant levels are shown in Table 7 and Figure 3. D1, D2, and D5 are positioned at the bottom (fifth) level, while D8 and D9 are positioned at the top (first) level. These findings indicate that vast bodies of water, a geographical location with solid 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. The remaining four drivers, D4, D3, D11, and D6 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.

4.2 Discussion on the findings

In the ISM results, it is interesting to note that D1, 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, D8, 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. The MICMAC approach employed to justify our ISM-based model by categorizing the drivers into four clusters: independent, dependent, linkage, and autonomous. This study determined D1, D2, D4, and D5 to be independent drivers, as they have strong driving power but weak dependence power, and D6, D8, and D9 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. The drivers D3 and D11 are identified as linkage drivers, meaning they function as links between independent and dependent variables. Hence, these drivers lie in the middle of the hierarchical model. This study 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, the drivers D1, D5, and D2 are identified 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 and the SDGs. These three drivers (D1, D5, and D2) will prompt the country to adopt policies that are more favourable to the implementation of sustainable solar energy initiatives by expanding the scope of investment, manufacturing, and employment.

4.3 Comparison of study findings with existing literature

The findings of this study largely align with those of previous studies. Several studies have already noted Bangladesh's tropical location and the resultantly strong potential for solar energy (e.g., Khan, 2018; Podder et al., 2021). This lines up with D1 receiving the highest weight in the BWM ranking and the highest driving power in the ISM hierarchy. In our study, the BWM ranked integration opportunity and peer-to-peer energy trading in the second-to-last and last positions, respectively. These findings align with previous research. According to Chowdhury (2020), grid integration has enormous potential, though on-grid households and industrial users have yet to reap its full advantages. 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.

It is worth discussing how this study 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 receiving 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 Bangladesh has made significant contributions to the overall development of the country's solar power sector. Nevertheless, this technology has outstanding potential—especially in the context of a densely populated country like Bangladesh—to significantly contribute to the overall development of the national energy framework (Chowdhury et al., 2020; Miah et al., 2021).

4.4 Implications

Based on our findings, action plans may be devised to boost the sustainability of development measures. For instance, a vigorous campaign and training program on the comparative advantages of solar energy could be highly effective in increasing awareness. Focusing on utility-scale solar PV plants, like in the neighbouring countries of India and China, could boost overall development. Moreover, behavioural change among prosumers regarding energy usage could encourage the integration of the prosumer-based direct-current nano-grid system with the utility grid, making peer-to-peer energy-sharing practices more efficient.

The findings from this study also suggest that focusing on independent drivers—by, for example, implementing policies aimed at boosting renewable energy and expanding FSPVs on large bodies of water—could significantly boost overall development. Government agencies can review existing energy policies to do away with 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.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

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 impact 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.

Still, this research has the following limitations.

- The research was mostly based on the subjective judgments of academic and industrial experts working in the Bangladeshi solar energy sector. Hence, the model lacks validation based on real-life scenarios.
- The expert feedback used in the BWM and ISM techniques may be biased, which would lead to unbalanced results. This study focused on just 12 key drivers—an inexhaustive list.

- The overall status of solar energy in Bangladesh is constantly changing, meaning that this study's findings may soon be outdated.

5.2 Recommendations for future research

- In the future, researchers can combine fuzzy sets with this study's BWM-ISM hybrid method to optimize the potential uncertainty and ambiguity in the crisp value inputs.
- Future study can also apply MCDM tools to the same problem in order to conduct a comparative analysis.
- Finally, researchers may use this study's integrated BWM and ISM-MICMAC hybrid tool to study the development of the solar energy sector—or other energy sectors—in other countries.

REFERENCES

Abuzeinab, A., Arif, M., and Qadri, M. A. (2017). Barriers to MNEs green business models in the UK construction sector: An ISM analysis. *Journal of Cleaner Production*, 160, 27–37. https://doi.org/10.1016/j.jclepro.2017.01.003

Ansari, M. F., Kharb, R. K., Luthra, S., Shimmi, S., and Chatterji, S. (2013). Analysis of barriers to implement solar power installations in India using interpretive structural modeling technique. *Renewable and Sustainable Energy Reviews*, 27, 163–174. https://doi.org/10.1016/j.rser.2013.07.002

Attri, R., Dev, N., Sharma, V. (2013) Interpretive structural modelling (ISM) approach: an overview. *Research Journal of Management Sciences 2319*, 1171

Attri, R., and Grover, S. (2018). Analysis of work-system design stage of production system life cycle using integrated ISM-MIMBI analysis. *International Journal of Operational Research*, 31(1), 24. https://doi.org/10.1504/ijor.2018.088556

Beikkhakhian, Y., Javanmardi, M., Karbasian, M., and Khayambashi, B. (2015). The application of ISM model in evaluating agile suppliers selection criteria and ranking suppliers using fuzzy TOPSIS-AHP methods. *Expert Systems with Applications*, 42(15–16), 6224–6236. https://doi.org/10.1016/j.eswa.2015.02.035

BPDB. (2020, October). *Annual report 2019–2020*. Bangladesh Power Development Board. Retrieved July 15, 2021, from https://tinyurl.com/paf8r8rn

Cherrafi, A., Elfezazi, S., Garza-Reyes, J. A., Benhida, K., and Mokhlis, A. (2017). Barriers in Green Lean implementation: a combined systematic literature review and interpretive structural modelling approach. *Production Planning and Control*, 28(10), 829–842. https://doi.org/10.1080/09537287.2017.1324184

Chowdhury, R., Aowal, M. A., Mostafa, S. M. G., and Rahman, M. A. (2020, October). Floating solar photovoltaic system: An overview and their feasibility at Kaptai in Rangamati. *2020 IEEE International Power and Renewable Energy Conference*. https://doi.org/10.1109/iprecon49514.2020.9315200

Chowdhury, S. A. (2020, December). *National Solar Energy Roadmap, 2021 - 2041*. Sustainable and Renewable Energy Development Authority (SREDA). Retrieved July 11, 2021, from https://tinyurl.com/ytb5ptr5

Chowdhury, S. A., and Khan, M. Z. R. (2020, December). The net metering guideline of Bangladesh-Potential and way forward. *2020 11th International Conference on Electrical and Computer Engineering (ICECE)*. https://doi.org/10.1109/icece51571.2020.9393148

Colasante, A., D'Adamo, I., and Morone, P. (2021). Nudging for the increased adoption of solar energy? Evidence from a survey in Italy. Energy Research and Social Science, 74, 101978. https://doi.org/10.1016/j.erss.2021.101978

D'Adamo, I., Gastaldi, M., and Morone, P. (2020). The post COVID-19 green recovery in practice: Assessing the profitability of a policy proposal on residential photovoltaic plants. *Energy Policy*, 147, 111910. https://doi.org/10.1016/j.enpol.2020.111910

Do, T. N., Burke, P. J., Baldwin, K. G., and Nguyen, C. T. (2020). Underlying drivers and barriers for solar photovoltaics diffusion: The case of Vietnam. *Energy Policy*, *144*, 111561. https://doi.org/10.1016/j.enpol.2020.111561

Energy and Power. (2021, June 21). *ADB finds sites for 61MW floating solar plants. Energy and Power Magazine*. Retrieved July 13, 2021, from https://tinyurl.com/5yf3tw

Gopal, P. R. C., and Thakkar, J. (2016). Analysing critical success factors to implement sustainable supply chain practices in Indian automobile industry: a case study. *Production Planning and Control*, 27(12), 1005–1018. https://doi.org/10.1080/09537287.2016.1173247

Halder, P. (2016). Potential and economic feasibility of solar home systems implementation in Bangladesh. *Renewable and Sustainable Energy Reviews*, 65, 568–576. https://doi.org/10.1016/j.rser.2016.07.062

Harun, M. A. (2015, July). *The role of solar home system (SHS) in socio-economic development of rural Bangladesh* (Thesis). Brac University. http://dspace.bracu.ac.bd/xmlui/handle/10361/5049

Hernandez RR, Easter SB, Murphy-Mariscal ML, Maestre FT, Tavassoli M, Allen EB, et al. Environmental impacts of utility-scale solar energy. *Renew Sustain Energy Rev 2014*; 29:766–79

Hirose, K. (2012). 2011 Fukushima Dai-ichi nuclear power plant accident: summary of regional radioactive deposition monitoring results. *Journal of environmental radioactivity*, 111, 13-17.

IRENA. (2021). *Global Trends*. International Renewable Energy Agency. Retrieved July 13, 2021, from https://www.irena.org/Statistics/View-Data-by-Topic/Costs/Global-Trends

Irfan, M., Elavarasan, R. M., Hao, Y., Feng, M., and Sailan, D. (2021). An assessment of consumers' willingness to utilize solar energy in China: End-users' perspective. Journal of Cleaner Production, 292, 126008. https://doi.org/10.1016/j.jclepro.2021.126008

Ishraque, M. F., Shezan, S. A., Nur, J. N., and Islam, M. S. (2020). Optimal sizing and assessment of an islanded photovoltaic-battery-diesel generator microgrid applicable to a remote school of Bangladesh. *Engineering Reports*, 3(1). https://doi.org/10.1002/eng2.12281

Jenkins, L. M., Alvarez, R., and Jordaan, S. M. (2020). Unmanaged climate risks to spent fuel from US nuclear power plants: The case of sea-level rise. *Energy Policy*, 137, 111106.

Khan, I. (2019a). Drivers, enablers, and barriers to prosumerism in Bangladesh: A sustainable solution to energy poverty? *Energy Research and Social Science*, 55, 82–92. https://doi.org/10.1016/j.erss.2019.04.019

Khan, I. (2019b). Energy-saving behaviour as a demand-side management strategy in the developing world: the case of Bangladesh. *International Journal of Energy and Environmental Engineering*, 10(4), 493–510. https://doi.org/10.1007/s40095-019-0302-3

Khan, I. (2019c). Household factors and electrical peak demand: a review for further assessment. *Advances in Building Energy Research*, 1–33. https://doi.org/10.1080/17512549.2019.1575770

Khan, K. A. (2018). Renewable Energy Scenario in Bangladesh. *International Journal of Advance Research and Innovative Ideas in Education (IJARIIE)*, 4(5), International Journal of Advance Research and Innovative Ideas in Education (IJARIIE).

Khan, M. Z. H., and Alom, M. M. (2015). Greenhouse Effect in Bangladesh - Environmental Rules and Regulations Perspective, Journal of Multidisciplinary Engineering Science and Technology, vol. 2, no. 1, pp. 283-285.

Kirchhoff, H., and Strunz, K. (2019). Key drivers for successful development of peer-to-peer microgrids for swarm electrification. *Applied Energy*, 244, 46–62. https://doi.org/10.1016/j.apenergy.2019.03.016

Kumar, A., Ferdous, R., Luque-Ayala, A., McEwan, C., Power, M., Turner, B., and Bulkeley, H. (2019). Solar energy for all? Understanding the successes and shortfalls through a critical comparative assessment of Bangladesh, Brazil, India, Mozambique, Sri Lanka and South Africa. *Energy Research and Social Science*, 48, 166–176. https://doi.org/10.1016/j.erss.2018.10.005

Kwan, C. L. (2012). Influence of local environmental, social, economic and political variables on the spatial distribution of residential solar PV arrays across the United States. *Energy Policy*, 47, 332–344. https://doi.org/10.1016/j.enpol.2012.04.074

Liang, F., Brunelli, M., and Rezaei, J. (2020). Consistency issues in the best worst method: Measurements and thresholds. *Omega*, 96, 102175. https://doi.org/10.1016/j.omega.2019.102175

Liza, Z. A., Aktar, H., and Islam, M. R. (2020). Solar Energy Development and Social Sustainability: A Case Study on the Teknaf Solar Power Plant in Bangladesh. *Journal of Asian Energy Studies*, 4(1), 1–8. https://doi.org/10.24112/jaes.040001

Liza, Z. A., and Islam, M. R. (2020). Solar park: The next generation energy source in Bangladesh. *Journal of Energy Research and Reviews*, 9–19. https://doi.org/10.9734/jenrr/2020/v4i230121

Luthra, S., Govindan, K., Kharb, R. K., and Mangla, S. K. (2016). Evaluating the enablers in solar power developments in the current scenario using fuzzy DEMATEL: An Indian perspective. *Renewable and Sustainable Energy Reviews*, 63, 379–397. https://doi.org/10.1016/j.rser.2016.04.041

Luthra, S., Kumar, V., Kumar, S., and Haleem, A. (2011). Barriers to implement green supply chain management in automobile industry using interpretive structural modeling technique: An Indian perspective. *Journal of Industrial Engineering and Management*, 4(2). https://doi.org/10.3926/jiem.2011.v4n2.p231-257

Marzia, K., Hasan, M. F., Miyazaki, T., Saha, B. B., and Koyama, S. (2018). Key Factors of Solar Energy Progress in Bangladesh until 2017. *Evergreen*, 5(2), 78–85. https://doi.org/10.5109/1936220

Mekhilef, S., Saidur, R., and Safari, A. (2011). A review on solar energy use in industries. *Renewable and Sustainable Energy Reviews*, 15(4), 1777–1790. https://doi.org/10.1016/j.rser.2010.12.018

Menon, R. R., and Ravi, V. (2021). Analysis of barriers of sustainable supply chain management in electronics industry: An interpretive structural modelling approach. *Cleaner and Responsible Consumption*, 3, 100026. https://doi.org/10.1016/j.clrc.2021.100026

Miah, M. A. R., Rahman, S. R., and Kabir, R. (2021, April). Techno-Economic analysis of floating solar PV integrating with hydropower plant in Bangladesh. *2021 IEEE Green Technologies Conference (GreenTech)*. https://doi.org/10.1109/greentech48523.2021.00016

Moktadir, M. A., Ali, S. M., Jabbour, C. J. C., Paul, A., Ahmed, S., Sultana, R., and Rahman, T. (2019). Key factors for energy-efficient supply chains: Implications for energy policy in emerging economies. *Energy*, 189, 116129. https://doi.org/10.1016/j.energy.2019.116129

Moktadir, M. A., Rahman, T., and Ali, S. M. (2017). Critical Success Factors in Implementing Green Supply Chain Management Practices in Footwear Industry in Bangladesh–An

Interpretive Structural Modeling Approach. In *1st Int. Conf. Business Manag.(ICBM)* (pp. 447-452).

Mondal, M. A. H., and Islam, A. S. (2011). Potential and viability of grid-connected solar PV system in Bangladesh. *Renewable Energy*, 36(6), 1869–1874. https://doi.org/10.1016/j.renene.2010.11.033

Moslem, S., Gul, M., Farooq, D., Celik, E., Ghorbanzadeh, O., and Blaschke, T. (2020). An integrated approach of Best-Worst method (BWM) and triangular fuzzy sets for evaluating driver behavior factors related to road safety. *Mathematics*, 8(3), 414. https://doi.org/10.3390/math8030414

Mostafaeipour, A., Alvandimanesh, M., Najafi, F., and Issakhov, A. (2021). Identifying challenges and barriers for development of solar energy by using fuzzy best-worst method: A case study. *Energy*, 226, 120355. https://doi.org/10.1016/j.energy.2021.120355

Nicholas, S., and Ahmed, S. J. (2020). *Bangladesh power review*. The Institute for Energy Economics and Financial Analysis. Retrieved July 15, 2021, from https://tinyurl.com/899rnjk5

Nurunnabi, M., Roy, N. K., and Mahmud, M. A. (2018). Investigating the environmental and socio-economic impacts of grid-tied photovoltaic and on-shore wind systems in Bangladesh. *IET Renewable Power Generation*, 12(9), 1082–1090. https://doi.org/10.1049/iet-rpg.2017.0751

Ohunakin, O. S., Adaramola, M. S., Oyewola, O. M., and Fagbenle, R. O. (2014). Solar energy applications and development in Nigeria: Drivers and barriers. *Renewable and Sustainable Energy Reviews*, 32, 294–301. https://doi.org/10.1016/j.rser.2014.01.014

Palit, D. (2013). Solar energy programs for rural electrification: Experiences and lessons from South Asia. *Energy for Sustainable Development*, 17(3), 270–279. https://doi.org/10.1016/j.esd.2013.01.002

Podder, A. K., Habibullah, M., Roy, N. K., and Pota, H. R. (2021). A chronological review of prospects of solar photovoltaic systems in Bangladesh: Feasibility study analysis, policies, barriers, and recommendations. *IET Renewable Power Generation*, 15(10), 2109–2132. https://doi.org/10.1049/rpg2.12165

Power System Master Plan 2016. (2016, September). Power Division, Ministry of Power, Energy and Mineral Resources, Government of the People's Republic of Bangladesh. https://mpemr.gov.bd/assets/media/pdffiles/FR_PSMP_revised.pdf

Ravi, V., and Shankar, R. (2005). Analysis of interactions among the barriers of reverse logistics. *Technological Forecasting and Social Change*, 72(8), 1011–1029. https://doi.org/10.1016/j.techfore.2004.07.002

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, 53, 49–57. https://doi.org/10.1016/j.omega.2014.11.009

Rezaei, J. (2020). A concentration ratio for nonlinear best worst method. *International Journal of Information Technology and Decision Making*, 19(03), 891–907. https://doi.org/10.1142/s0219622020500170

Schelly, C., and Letzelter, J. C. (2020). Examining the Key Drivers of Residential Solar Adoption in Upstate New York. *Sustainability*, 12(6), 2552. https://doi.org/10.3390/su12062552

Sharif, A., Meo, M. S., Chowdhury, M. A. F., and Sohag, K. (2021). Role of solar energy in reducing ecological footprints: An empirical analysis. *Journal of Cleaner Production*, 292, 126028. https://doi.org/10.1016/j.jclepro.2021.126028

Sharma, H., Gupta, A., and Sushil. (1995). The objectives of waste management in India: A futures inquiry. *Technological Forecasting and Social Change*, 48(3), 285–309. https://doi.org/10.1016/0040-1625(94)00066-6

Song, D. W., Seo, Y. J., and Kwak, D. W. (2019). Learning from Hanjin Shipping's failure: A holistic interpretation on its causes and reasons. *Transport Policy*, 82, 77–87. https://doi.org/10.1016/j.tranpol.2018.12.015

SREDA. (2016, May). *Energy efficiency and conservation master plan up to 2030*. Sustainable and Renewable Energy Development Authority. Retrieved July 12, 2021, from https://tinyurl.com/y2m8tv82

SREDA. (2021, June). *Net metering rooftop solar program*. Sustainable and Renewable Energy Development Authority. Retrieved July 12, 2021, from http://www.sreda.gov.bd/site/page/8dff5b3d-6f92-4b63-86c6-8d3745477db1/-

Uddin, M. I., Islam, M. R., Awal, Z. I., and Newaz, K. M. S. (2017). An analysis of accidents in the inland waterways of Bangladesh: Lessons from a decade (2005–2015). Procedia Engineering, 194, 291–297. https://doi.org/10.1016/j.proeng.2017.08.148

UNEP. (2020). *Emissions gap report 2020 - executive summary*. United Nations Environment Programme (UNEP) and UNEP DTU Partnership (UDP). https://www.unep.org/emissions-gap-report-2020

Warfield, J. N. (1974). Developing Interconnection Matrices in Structural Modeling. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-4*(1), 81–87. https://doi.org/10.1109/tsmc.1974.5408524

Whiteside, M., and Herndon, J. M. (2018). Coal fly ash aerosol: Risk factor for lung cancer. *Journal of Advances in Medicine and Medical Research*, 1-10.

World Bank. (2016, May 26). *Sustainable development goal on energy (SDG 7) and the world bank group*. Retrieved July 14, 2021, from https://tinyurl.com/4a639yha

Yoshida, N., and Takahashi, Y. (2012). Land-surface contamination by radionuclides from the Fukushima Daiichi Nuclear Power Plant accident. *Elements*, 8(3), 201-206.

Zhang, C., Wu, J., Zhou, Y., Cheng, M., and Long, C. (2018). Peer-to-Peer energy trading in a microgrid. Applied Energy, 220, 1–12. https://doi.org/10.1016/j.apenergy.2018.03.010

Zhang, Y., Song, J., and Hamori, S. (2011). Impact of subsidy policies on diffusion of photovoltaic power generation. *Energy Policy*, 39(4), 1958–1964. https://doi.org/10.1016/j.enpol.2011.01.021

Zhao, Z. Y., Chen, Y. L., and Li, H. (2019). What affects the development of renewable energy power generation projects in China: ISM analysis. *Renewable Energy*, 131, 506–517. https://doi.org/10.1016/j.renene.2018.07.063

Zierold, K. M., and Odoh, C. (2020). A review on fly ash from coal-fired power plants: chemical composition, regulations, and health evidence. *Reviews on environmental health*, 35(4), 401-418.

APPENDIX

Appendix A: Questionnaire for the identification of the relevant drivers

Q.1: What is your role in the solar energy field in Bangladesh?

Q.2: How many years of experience do you have of working on solar energy in Bangladesh?

Q.3: Please identify the relevant drivers for the development of sustainable solar energy in Bangladesh from the following list of drivers. If a driver is relevant to the growth of this sector in the context of Bangladesh, please write 'Yes'; otherwise write 'No'. Moreover, you can add any other driver that you deem important for sustainable solar energy development in Bangladesh.

Driving factors	Relevant: write 'Yes'; Irrelevant: write 'No'
Favorable geographical location in terms of solar irradiation	
The need to reduce greenhouse gas emission	
Support for industrialization	
Govt. policy towards SRE	
Cheaper energy alternative	
Peer-to-peer (P2P) energy trading	
Convenience	
Socio-economic development	
Integration opportunity	
Scope for investment and employment	

Appendix B: Description of the Drivers

Table B1. Description of identified key drivers

Code	Driver name	Description
D1	Favorable geographical location in terms of solar irradiation	Bangladesh is situated between 20.30 - 26.38° north latitude and 88.04 - 92.44° east longitude with an area of 147570 km^2. The daily incident of solar irradiance varies between 4 and 6.5 kWh/m^2, which makes it an ideal location for harvesting this abundant source of green energy (Mondal and Islam, 2011). According to Podder et al. (2021), the energy consumption of Bangladesh was 1.75×1018 J in 2019, which could have been met by using just 0.17% of the absolute solar radiation accessible within the country. Hence, Bangladesh is grossly underutilizing its potential to harness the amount of solar energy that is currently naturally accessible to it.
D2	The need to reduce GHG emission	Due to the burning of fossil fuels like natural gas, coal, oil, etc., GHG emission increases every year. This emission contributes to the rise in global warming, which in turn contributes to the rise in temperature and sea level (Khan and Alom, 2015). To follow the Paris Climate Agreement, which was signed by Bangladesh, the country needs to increase its' focus on solar energy initiatives to play its role in limiting the rise in global temperature.

Code	Driver name	Description
D3	Support for industrialization	Despite having an agriculture-dependent economy, Bangladesh is trying to gear up industrialization with a vision to become one of the developed nations in near future. The industrial sector of the country is the biggest user in the power sector. In this aspect, solar power has drawn a lot of attention, among all the renewable energy sources, as the most promising option to be utilized on an industrial scale (Mekhilef et al., 2011). Especially the Readymade Garments Industry (RMG) sector, which is currently the backbone of the country's economy, has scopes to partially satisfy its power need from solar energy and reduce its dependency on the power supplied from the national grid. (Chowdhury and Khan, 2020).
D4	Govt. policy towards SRE	The commitment of the government to ensure energy security is an important driver for the long-term development of solar energy in any country. Government policy plays a crucial role to ease the processes of availing necessary resources like land acquisition, transmission tower establishment, etc. for solar power plant establishment. Subsidies, policies, tariffs, licenses, setting standards, and other policies related to the energy sector are also controlled by different government agencies, which can significantly impact the growth of this sector as well.

Code	Driver name	Description
D5	Large bodies of water	Rivers are an important geomorphic feature of Bangladesh, which has a massive river network, including around 700 rivers and their distributaries, with a total length of about 24000 kilometres (Uddin et al., 2017). This abundance of water bodies in Bangladesh has enormous potential for installing FSPV plants. FSPV plants are gaining popularity worldwide because of the lower cost and higher availability of unobstructed water surfaces and its higher efficiency. A FSPV system is capable of maintaining lower module temperature in the vicinity of water and thus can provide better efficiency compared to land-based PV systems (Chowdhury et al., 2020).
D6	Cheaper energy alternative	Due to the decline in PV module price and balance-of-system cost, the weighted average of total PV installation cost has gone down by 78.85% globally from 2010 to 2019 (IRENA, 2021). This economic prospect is very promising for the growth of the PV industries in Bangladesh. Due to lower labour costs compared to the other countries, the cost of solar system development in Bangladesh is expected to reduce even further. Solar Home System (SHS) is also economically beneficial and sustainable in Bangladesh, especially for the small-scale rural businesses and household lighting, along with powering small electronic appliances.

Code	Driver name	Description
D7	Peer-to-peer (P2P) energy trading	Peer-to-Peer (P2P) energy trading represents a direct energy trading between the peers, where energy extracted from small-scale sources like residential houses, offices, factories, etc, is traded among local energy prosumers and consumers (Zhang et al., 2018). This P2P energy sharing concept intends to utilize the wasted potion of the annually generated solar power. Bangladesh can easily tap into this vast underutilized potential energy reserve. Monetary reward for sharing electricity, ability to meet given power demand with reliability, ability to support larger loads, user-friendliness, clear ownership roles for equipment are the key factors that can motivate these SHS users to join the peer-to-peer microgrid community (Kirchhoff and Strunz, 2019; Colasante et al., 2021).
D8	Convenience	In remote areas, distribution line setup is more expensive due to the challenging landscapes, dominated by mostly marshlands, hills, rivers, and islands. Furthermore, many areas are highly susceptible to natural disasters like floods, river erosion, etc. In these regions, a decentralized electricity supply with sustainable and renewable source represents a more feasible alternative than grid electrification (Harun, 2015). Solar energy can reach areas where grid extension is challenging and expensive. Solar systems are relatively easy to install and operate and can bring many benefits to the communities, who lives in those remote areas.

Code	Driver name	Description
D9	Socio-economic development	Communities benefit socially and economically when they have access to a reliable, affordable, and sustainable energy supply. For example, until 2019, about 4.13 million SHSs have been installed in the areas of Bangladesh where grid expansion is challenging and expensive (World Bank, 2016). These off-grid SHS have a wide range of impacts on the quality of life in the rural areas, including extending study hours for students after sunset, accessibility of information via cell phone and TV, ensuring home safety, providing uninterrupted irrigation by using solar irrigation systems, local preservation of sensitive medicines or vaccines, operating cold storage, improving indoor air quality by substituting kerosene lanterns, night trading, and so on (Harun, 2015).
D10	Integration opportunity	Though the off-grid solar home system program was a great success across the globe, the grid-connected PV electricity has huge potentials as well. The prospect of standalone SHS is immense in the distant and remote areas, which are far from the coverage of the national grid or the areas that receive interrupted supply. Grid-connected PV systems have a potential market in heavily populated cities as well. According to Mondal and Islam (2011), a 1-MW grid-connected solar PV system in Bangladesh has the potential to generate electricity up to 1.85 GWh annually as examined.

Code	Driver name	Description
D11	Scope for investment and employment	Government's initiatives to enable, encourage and facilitate both public and private sector investment in renewable energy projects have opened up opportunities to invest in various solar energy projects. Some of the incentives are in the form of some types of tax exemptions. The solar panel industry is also creating job opportunities for women. This has been made possible by Grameen Shakti, a non-profit organization, who has provided training to the rural women of Bangladesh from 2005 to 2010 intending to integrate them into the value chain of SHS (Palit, 2013). This resulting employment generation and value addition through this green technology are helping to boost the economy of the region.
D12	Mass awareness	Mass awareness is an important driver for the adoption and expansion of solar energy in Bangladesh. The government of Bangladesh has already taken several initiatives to raise public awareness about the importance of sustainable renewable energy and energy conservation. Intention factors like the awareness of solar energy systems and believing the true potential of solar energy, had a significant impact on the willingness to utilize solar energy systems in China and Iran (Irfan et al., 2021). Hence, it is reasonable to assume that awareness can act as an important driver for the expansion of solar energy systems in other parts of the developing world as well.

Appendix C: Interpretive structural modeling

The steps in the procedure of the ISM model formation is presented below (Gopal and Thakkar, 2016; Attri and Grover, 2018; Ansari et al., 2013).

Step 1: Identifying the criteria to be studied. In this research work, drivers of solar power development in Bangladesh have been considered as criteria.

Step 2: Finding the contextual relationship among the drivers identified in step 1 by the expert. For analysing the driving factors, a contextual relationship of 'leads to' or 'influences' between every two factors (i and j) has been chosen by the expert. Several symbols have been used to denote the direction of relationship: (a) V when factor i will influence or lead to factor j) (b) A when factor j will influence or lead to factor j (c) X when factor i and j will influence or lead to each other (d) O when i and j are unrelated.

Step 3: Constructing a structural self-interaction matrix (SSIM) to indicate a pairwise relationship among the criteria.

Step 4: The SSIM is converted into a Reachability Matrix (RM) by substituting the four symbols (i.e., V, A, X or O) of SSIM by 1s or 0s.

Table C1. Rules for substituting SSIM symbols

Entry in SSIM	Value of *(i,j)* entry in RM	Value of *(j,i)* entry in RM
V	1	0
A	0	1
X	1	1
O	0	0

Following the substitution rules shown in Table C1, the initial reachability matrix is prepared. The matrix is then checked for transitivity and 1* entries are included to fill any gap in the SSIM. After incorporating the transitivity, the final reachability matrix is formed.

Step 5: Level partitioning has been done on the final RM obtained in Step 4 by deriving the reachability sets and antecedent sets of each factor. The reachability set of a driver is formed by the driver itself and other drivers that are influenced by it. The antecedent set of a driver is formed by the driver itself and the other drivers which may influence it. Intersection set is found from the common elements of both the reachability and antecedent sets. The drivers for which the reachability set is identical to its intersection set have been placed in Level 1 in the ISM hierarchy. After fixing and removing the factors in the first level the cycle has been repeated until all the drivers are grouped into levels.

Step 6: From the contextual relationships in the RM, a directed graph has been drawn. After removing the transitive links, a final digraph has been developed.

Step 7: Factor nodes have been replaced with relationship statements. In this way, the final interpretive structural model has been developed.

Step 8: The developed model has been assessed to check for any conceptual irregularity. If there was any inconsistency, necessary modifications have been done by the expert.

Appendix D: Questionnaire for the best and the worst drivers

Q.1 Please choose the best and worst drivers from the following list

Code	Drivers	Best (most significant) driver	Worst (least significant) driver
D1	Favorable geographical location in terms of solar irradiation		
D2	The need to greenhouse gas emission		
D3	Support for industrialization		
D4	Govt. policy towards SRE		
D5	Large bodies of water		
D6	Cheaper energy alternative		
D7	Peer-to-peer (P2P) energy trading		
D8	Convenience		
D9	Socio-economic development		
D10	Integration opportunity		
D11	Scope for investment and employment		
D12	Mass awareness		

Q.2: Please fill in the table below, ranking the drivers on linguistic scale from 1 to 9

Expert Name		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
	Best												
	Worst												

Appendix E: Experts' opinion for Drivers analysis

Table E1: Experts' feedback on BWM

Code	Name of the Drivers	Best drivers identified by decision maker	Worst drivers identified by decision maker
D1	Favorable geographical location in terms of solar irradiation	EX-1, EX-5, EX-6	
D2	The need to reduce greenhouse gas emission	EX-7	
D3	Support for industrialization		
D4	Govt. policy towards SRE	EX-2, EX-4	
D5	Large bodies of water		
D6	Cheaper energy alternative		
D7	Peer-to-peer (P2P) energy trading		EX-5, EX-7
D8	Convenience		EX-4, EX-6
D9	Socio-economic development		
D10	Integration opportunity		EX-1, EX-3
D11	Scope for investment and employment	EX-3	
D12	Mass awareness		EX-2

Table E2: Experts' scoring on a scale of 1 to 9 and optimal weightage of each driver

Expert		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Expert 1	Best (D1)	1	2	4	3	7	5	7	6	5	9	3	6
	Worst (D10)	9	8	6	7	3	5	3	4	5	1	7	4
	Weighting (ξ^{L*}=0.0536)	0.2468	0.1502	0.0751	0.1001	0.0429	0.0601	0.0429	0.0501	0.0601	0.0215	0.1001	0.0501
Expert 2	Best (D4)	2	3	8	1	4	5	6	6	5	7	4	9
	Worst (D12)	8	7	2	9	6	5	4	4	5	3	6	1
	Weighting (ξ^{L*}=0.0553)	0.0553	0.1549	0.1033	0.0387	0.2545	0.0775	0.0620	0.0516	0.0516	0.0620	0.0443	0.0775
Expert 3	Best (D11)	2	5	2	3	3	6	6	4	8	9	1	5
	Worst (D10)	8	5	8	7	7	4	4	6	2	1	9	5
	Weighting (ξ^{L*}=0.0487)	0.1363	0.0545	0.1363	0.0909	0.0909	0.0454	0.0454	0.0682	0.0341	0.0195	0.2240	0.0545
Expert 4	Best (D4)	2	4	8	1	5	3	8	9	3	6	4	5
	Worst (D8)	8	6	2	9	5	7	2	1	7	4	6	5
	Weighting (ξ^{L*}=0.0529)	0.1481	0.0740	0.0370	0.2433	0.0592	0.0987	0.0370	0.0212	0.0987	0.0494	0.0740	0.0592

Expert		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Expert 5	Best (D1)	1	2	4	8	7	5	9	4	8	5	3	6
	Worst (D7)	9	8	6	2	3	5	1	6	2	5	7	4
	Weighting (ξ^{L*}=0.0561)	0.2578	0.1570	0.0785	0.0392	0.0448	0.0628	0.0224	0.0785	0.0392	0.0628	0.1046	0.0523
Expert 6	Best (D1)	1	2	7	2	4	6	8	9	6	7	5	7
	Worst (D8)	9	8	3	8	6	4	2	1	4	3	5	3
	Weighting (ξ^{L*}=0.0553)	0.2543	0.1548	0.0442	0.1548	0.0774	0.0516	0.0387	0.0221	0.0516	0.0442	0.0619	0.0442
Expert 7	Best (D2)	2	1	4	3	7	6	9	5	8	7	4	7
	Worst (D7)	8	9	6	7	3	4	1	5	2	3	6	3
	Weighting (ξ^{L*}=0.0568)	0.1589	0.2611	0.0795	0.1059	0.0454	0.0530	0.0227	0.0636	0.0397	0.0454	0.0795	0.0454

Appendix F: Level partitioning

Table F1. Level partitioning of the drivers: first iteration

Drivers	Reachability set	Antecedent set	Intersection set	Level
D1	D1,D3,D4,D6,D8,D9,D11	D1	D1	
D2	D2,D3,D4,D6,D8,D9,D11	D2	D2	
D3	D3,D6,D8,D9,D11	D1,D2,D3,D4,D5,D11	D3,D11	
D4	D3,D4,D6,D8,D9,D11	D1,D2,D4,D5	D4	
D5	D3,D4,D5,D6,D8,D9,D11	D5	D5	
D6	D6,D8,D9	D1,D2,D3,D4,D5,D6,D11	D6	
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	

Table F2. Level partitioning of the drivers: second iteration

Drivers	Reachability set	Antecedent set	Intersection set	Level
D1	D1,D3,D4,D6,D11	D1	D1	
D2	D2,D3,D4,D6,D11	D2	D2	
D3	D3,D6,D11	D1,D2,D3,D4,D5,D11	D3,D11	
D4	D3,D4,D6,D11	D1,D2,D4,D5	D4	
D5	D3,D4,D5,D6,D11	D5	D5	
D6	D6	D1,D2,D3,D4,D5,D6,D11	D6	II
D11	D3,D6,D11	D1,D2,D3,D4,D5,D11	D3,D11	

Table F3. Level partitioning of the drivers: third iteration

Drivers	Reachability set	Antecedent set	Intersection set	Level
D1	D1,D3,D4,D11	D1	D1	
D2	D2,D3,D4,D11	D2	D2	
D3	D3,D11	D1,D2,D3,D4,D5,D11	D3,D11	III
D4	D3,D4,D11	D1,D2,D4,D5	D4	
D5	D3,D4,D5,D11	D5	D5	
D11	D3,D11	D1,D2,D3,D4,D5,D11	D3,D11	III

Table F4. Level partitioning of the drivers: fourth iteration

Drivers	Reachability set	Antecedent set	Intersection set	Level
D1	D1,D4	D1	D1	
D2	D2,D4	D2	D2	
D4	D4	D1,D2,D4,D5	D4	IV
D5	D4,D5,D11	D5	D5	

Table F5. Level partitioning of the drivers: fifth iteration

Drivers	Reachability set	Antecedent set	Intersection set	Level
D1	D1	D1	D1	V
D2	D2	D2	D2	V
D5	D5	D5	D5	V