Thematic Section: “Green Transition and National Efforts towards Net-Zero Target”

WHAT TO FOCUS ON IN ORDER TO ACCELERATE ACCESS TO MODERN ENERGY SERVICES AND ENERGY USE EFFICIENCY IN BANGLADESH

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Consistent with national priorities: How can a rapidly growing country, such as Bangladesh, overcome the barriers to realizing Sustainable Development Goal 7? The present study includes an analysis of the barriers to achieving 24x7 access to modern energy and the required improvements to make energy more efficient to overcome them in Bangladesh. Interpretive structural modeling (ISM) is applied to identify the interactions among the barriers as laid out in context-relevant scientific literature. The Cross-impact matrix multiplication applied to classification (MICMAC) is applied to classify the barriers. The results indicate that the barriers can be addressed through a systematic packaging and prioritization approach.

Keywords: Sustainable Development Goal 7; barrier analysis; interpretive structural modeling, rapidly growing economy, developing country

JEL classification: O13, Q49, Q56

I. INTRODUCTION

Bangladesh, one of the most rapidly growing economies in South Asia, recorded annual gross domestic product (GDP) growth of 7.9 per cent in 2019 (World Bank, 2020). To put into context, in Asia, the Republic of Korea and Singapore recorded a GDP annual growth rate that exceeded 8 per cent from1966 to 1990; China recorded annual GDP growth of 9.8 per between 1978 and 2009; Malaysia recorded annual GDP growth of 7.37 per cent from 1961 to 1997. (Mahmud and Roy, 2020). Bangladesh aspires to achieve developed nation status by 2041. Under the national government initiative entitled "Vision 2021" Bangladesh had set a goal of universal access to energy by 2021 (Bangladesh, Ministry of Planning, 2020) and achieved 96.2 per cent access in 2020 (SDG Cell, 2020). More than 88 per cent of the Bangladeshi households have access to electricity; 82 per cent get it from the grid and 6.1 per cent get it from off-grid sources, but 65 per cent of the households experience more than 14 outages per week. For 47 per cent of the households that can use medium- to high-load appliances, electricity is available for at least 8 hours per day and 3 hours per evening. Only 2.6 per cent has 23 hours of electricity service per day with 4 hours of outages per evening and is capable of using very high-power load appliances (Samad and others, 2019).

Over the past forty years, innovations, policies and implementation of energy efficiency initiatives have been proven to be highly effective across various country contexts. Energy efficiency programmes in many countries and sectors have successfully reduced energy use per unit of economic output and led to net improvements in welfare or emission reductions, or in both of them (Saunders and others, 2021). In many countries and many sectors, however, energy efficiency improvements are possible, but gaps persist due to multiple barriers. Among the Asian countries, China, India and Singapore, were able to keep their energy/GDP ratio at less than one during their rapidly growing economic phase whereas the economies of Bangladesh, Malaysia and the Republic of Korea had been expanding while at the same time increasing their energy use per GDP (Roy and others, 2021). Energy efficiency is a critical component of societies' response to the challenges of climate change, economic development and energy security (IEA, 2013). The existing energy efficiency at various industrial activities vis-à-vis the international benchmark and saving potential in Bangladesh show that there is plenty of room for improvement in many industries in this regard, including, among them, those engaged in textiles and steel. (Hartley-Louis and Islam, 2018).

Sustainable Development Goal 7 (affordable and clean energy) is focused on three areas: renewable energy penetration; modern energy access; and energy efficiency improvement by 2030.[1] For this analysis, a comprehensive list of barriers to the accelerated penetration of renewable energy in Bangladesh was developed and the hierarchy among the various individual barriers was analysed (Mahmud and Roy, 2021). Many researchers have attempted to identify specific barriers to 24/7 modern energy access and energy efficiency improvements in Bangladesh, however, no comprehensive literature covering the country exists. However, it is available in other country contexts (Zhao, Chen and Li, 2019), and can be used to illuminate the interconnections and hierarchy among these barriers to help in formulating policy recommendations (Mahmud and Roy and others, 2021). Specific contributions of this present study are to fill this gap in the literature in the context of Bangladesh through the following:

(a) Identification of a list of barriers through a literature review that have been hindering the improvement of 24/7 modern energy access and overall energy efficiency.

(b) Understanding the hierarchical structure of the barriers to obtain a clear understanding of the various layers of the barriers.

(c) Categorizing the barriers as driving barriers, dependent barriers, independent barriers and autonomous barriers to help in guiding actions for overcoming these barriers systematically.

Section 2 gives a description of the methods, materials and research tools used for the analysis the results and discussion are presented in section 3, followed by the conclusions in section 4.

II. METHODS, MATERIALS AND RESEARCH TOOLS

A review of methods in the literature (Mahmud and Roy, 2021) clearly shows the advantage of applying the interpretive structural modeling (ISM) method supplemented by cross-impact matrix multiplication applied to classification (MICMAC) (Yadav and Barve, 2015). How a barrier system works is critical to understand what level of packaging or sequencing needs to adopted overcome them. The steps followed in the ISM process are shown in figure 1.

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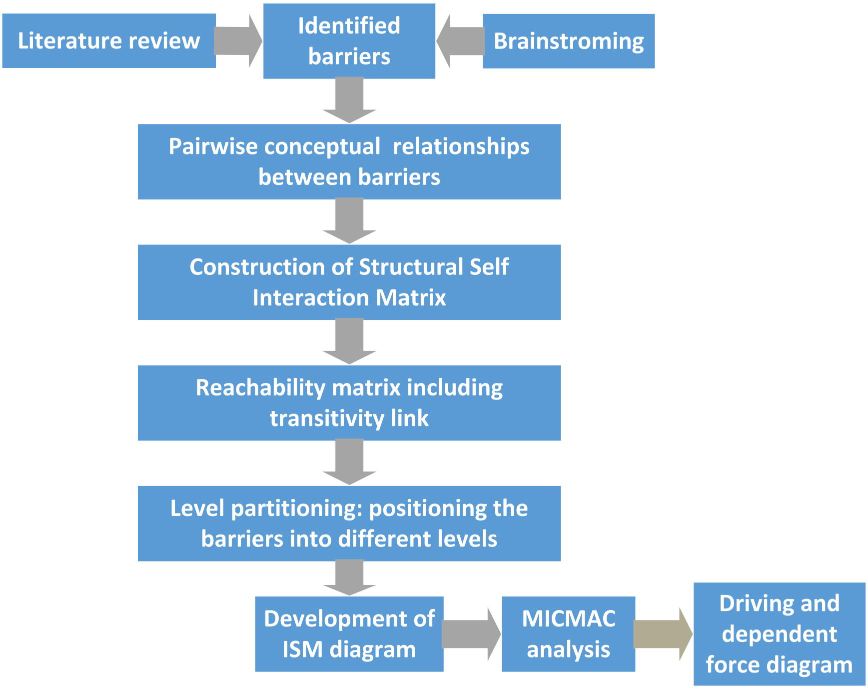
Figure 1. Steps followed in interpretive structural modeling



Source: Adapted from Mahmud and Roy (2021)

- Step 1: (a) A comprehensive list of barriers are identified from peer reviewed literature (boxes 1 and 2) and various official reports.
- Step 2: A pairwise conceptual relationship is established between the barriers to develop a structural self-interaction matrix (SSIM).
- Step 3: An initial reachability matrix is formed using SSIM through binary numbers. The final reachability matrix is developed by using the transitivity concept to obtain higher-order links to incorporate the indirect relationships among the barriers using the following relation:
    - o Element P related to Q;
    - o Q related to R;
    - o Implies R is necessarily related to P.

- Step 4: The barriers are positioned into different levels by using the final reachability matrix.
- Step 5: The ISM model is presented using the partitioned level and the relationship given in the reachability matrix.
- Step 6: Cross-impact matrix multiplication applied to classification analysis.
- Step 7: A final figure is developed to show clusters of barriers grouped by their driving power and dependence power.

Data for this study are qualitative in nature. Information about barriers are collected from published peer-reviewed literature on Bangladesh relevant to the objective of this study. From the literature review, an exhaustive list of 14 barriers for "'access to modern energy" ' (listed in box 1) and nine barriers to "energy efficiency improvement" (listed in box 2) are identified. The key applications for which the barriers are assessed are shown in table 1. The allocation of these barriers across eight major dimensions (Mahmud and Roy, 2021) are shown within parenthesis beside each barrier in boxes 1, 2 and 3. It is worth noting that each of the literature reviewed mentions one or the other, or a group of these barriers, but not the comprehensive list as compiled in this study, taking note of overlaps. The authors of this study have decided to identify the links among them without carrying out any further screening, as is sometimes performed by authors (Zhao, Chen and Li, 2019), and then conducted their hierarchy check following the steps mentioned in figure 1 for each of the focus areas.

Table 1. Key energy efficiency and energy access applications in Bangladesh to which the barriers apply

	Energy efficiency for	24/7 Energy access
	Power sector	**Power and energy supply**
1	High efficiency power generation by Combined cycle, tri-generation, multi energy output, among others.	Rural and urban distribution network modernization.
2	Transmission loss reduction, power factor Improvement, theft, leakage, among others.	Reducing peak demand through demand side management
3	Energy management in energy supply plants	Strengthening demand side energy conservation
4		Cross-border power trading

Table 1. *(continued)*

	Industry sector	
5	Efficient industrial process, waste heat recovery, among others	Replacement of captive power by grid power
6	Use of energy efficient technology for industrial motor, boiler, chiller, textile weaving, among others	Improved coordination among electricity generation, transmission and distribution utilities.
7	encourage advanced technology brick kiln and use of non-fired brick	Making the power grid smart, reliable and resilient
	Transport Sector	
8	Penetration of high efficiency vehicle, hybrid car, electric car	Automatic load management and generation scheduling,
9	Mass transportation system in urban area	Appropriate information disclosure mechanisms
10	Improved and enhanced Inland Water Transport (IWT) system	Development of domestic energy resources including offshore exploration in newly acquired sea area
11		Reliable and affordable grid power
	End-use appliances	
10	Use of energy efficient appliances such as split type, inverter type AC with a high coefficient of performance, and variable speed compressor; refrigeration with inverters and variable speed compressor; efficient fans.	Increased use of clean cooking fuels and efficient cooking stoves.
11	Efficient fluorescent lamp, LED bulbs	
	Policy instruments and behaviour change	
12	Appropriate energy pricing, subsidy reduction, time of use based pricing	Proper pricing
13	Change the lifestyle, such as sleeping with the lights off	Consistent policy implementation
14	Awareness raising programme	
15	Energy efficiency labelling programme, such as home appliance rating	

Table 1. *(continued)*

16	Energy Management Program involving, for example, an energy audit, benchmarking,, consumption reporting and large consumer dissemination
	Finance
17	Engage bank personnel on financing EE projects, stimulating investment in energy efficiency activity

Source: Prepared from the literature listed in boxes 1 and 2

Box 1. List of barriers relevant to Bangladesh to accelerate access to modern energy

1. Inefficiency, complexity and unbalanced evaluation of the value chain: (institutional barrier 1)

A bureaucratic culture, complex administrative environment and lack of coordination among generation, transmission and distribution results in policy implementation delays. Value chains involving the electrical and energy sectors, as well as the production, distribution, and transmission sectors, are not adequately explored. Another hurdle is the institutions' insufficient negotiating power for cross-border agreements (Haque, Dhakal and Mostafa, 2020; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; Sarker, 2017; Economist Intelligence Unit, 2018; Zaman and Brudermann, 2018).

2. Corruption (institutional barrier 2)

Such as illicit gas and electricity connections, meter manipulation, utility employee malfeasance, results in increased system loss and a low connection to bill ratio. These, in turn, increase consumer costs and reduce the energy sector's institutional efficiency (Haque, Dhakal and Mostafa, 2020; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; Sarker, 2017; Economist Intelligence Unit, 2018; Zaman and Brudermann, 2018).

3. Unfavorable political environment (policy and governance barrier 1)

Over an extended period of time in Bangladesh, the unpredictability of the political environment and the blame culture has led to the frequent alteration in policy direction and the execution cost of energy and climate-related policies. Political intervention, impact of local politics delays consistent policy formation or results in the implementation of incorrect policies (ADB, 2009; Amin and others, 2019; Haque, Dhakal and Mostafa, 2020; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; Sarker, 2017; World Bank, 2019; Zaman and Brudermann, 2018).

4. Top-down policymaking (policy and governance barrier 2)

Policies are developed using a top-down approach through a non-transparent centralized bureaucracy in which the participations of stakeholders are missing (ADB, 2009; Amin and others, 2019; Haque, Dhakal and Mostafa, 2020; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; Sarker, 2017; World Bank, 2019; Zaman and Brudermann, 2018).

5. Inefficient policies (policy and governance barrier 3)

Absence of a suitable energy policy to discourage the use of fossil fuels in power generation in accordance with the nationally distributed commitment (NDC) to climate objectives. Instead, present regulations promote inefficient captive power generation and high-cost quick rental power plants. The tariff policy lacks competitive tariffs, and energy tariffs are influenced by power tariffs. Furthermore, categorizing tariffs for various users does not account for the impact of this pricing on the corresponding user's economic activity (ADB, 2009; Amin and others, 2019; Haque, Dhakal and Mostafa, 2020; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; Sarker, 2017; World Bank, 2019; Zaman and Brudermann, 2018).

6. Unreliable grid power supply: (technical barrier 1)

Voltage fluctuations, insufficient capacity and failure to modernize the transmission and distribution system, lack of spinning reserves, inefficient dispatch procedures, and outages during peak hours all contribute to the unreliability of grid electricity. This encourages inefficient captive power generation, while also observing idle generation capacity (ADB, 2009; Amin and others, 2019; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; Zaman and Brudermann, 2018).

7. Exploration and infrastructural limitation for primary energy supply (technical barrier 2)

Inefficient primary energy exploration leads to a deficit in primary energy supply. Offshore exploration activity is very restricted; exploration is delayed due to sporadic changes in contract choices for gas exploration, despite successful exploration in the same maritime region by neighbouring countries. Coal exploration and production has a relatively limited track record of success. Port capacity is insufficient to fulfil the demand for imports for new power plants (ADB, 2009; Amin and others, 2019; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; Zaman and Brudermann, 2018).

8. Safety and efficiency (technical barrier 3)

The average efficiency of power plants is lower for low-efficient liquid-based power plants. The sluggish rate of smart prepayment meter installations increases system loss and decreases efficiency. The management safety and disposal of radioactive waste is a major problem associated with nuclear power plants that became operational by 2021 (ADB, 2009; Amin and others, 2019; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; Zaman and Brudermann, 2018).

9. Inappropriate subsidy allocation and lack of appropriate tariff policy: (economic and financial barrier 1)

The energy subsidy is irrational and trapped in supporting fossil fuel; there is also no long-term tariff strategy for the subsidy. A market-based tariff is missing (ADB, 2009; Amin and others, 2019; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; World Bank, 2019; Zaman and Brudermann, 2018).

10. Inefficient financing and donor dependent policy (economic and financial barrier 2)

Inadequate financing facility, shortage of long-term capital and dependency on donor agencies hinder progress for reliable excess to modern energy. The policy advice of a donor agency influences the development of energy infrastructure and imbalances the interests of local investors and stakeholders and national policymakers. Additionally, power sector entrepreneurs are more interested in investing in generation rather than transmission and distribution (ADB, 2009; Amin and others, 2019; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; World Bank, 2019; Zaman and Brudermann, 2018).

11. High cost of grid power and increasing cost of doing business (economic and financial barrier 3)

Expensive liquid fuel, imported liquefied natural gas (LNG), and debt burdens increase the costs for energy-intensive heavy industry (ADB, 2009;

Amin and others, 2019; Hossain, 2020; Islam and others, 2014; Moazzem and Ali, 2019; World Bank, 2019; Zaman and Brudermann, 2018).

12. Depleting local gas reserve and fossil dependency: (resource and environmental barriers)

Depleting local gas reserves creates dependency on imported costlier LNG and reduces the supply of primary energy at affordable prices. Limited supply of local gas promotes expensive liquid-based power generation. Fossil fuel dependency raise emissions over time (Hossain, 2020; Moazzem and Ali, 2019; Economist Intelligence Unit, 2018; World Bank, 2019; Zaman and Brudermann, 2018).

13. Limited disclosure and inaccurate information: (informational barrier)

Informational limitation is a significant barrier. The information disclosure mechanism is very limited. Asymmetric reporting and data variations are common for energy-related information. Absence of accurate demand forecasting in relation to economic activity results in idle generation capacity (Hossain, 2020; Zaman and Brudermann, 2018).

14. Limited cooperation and transactional complexity (geopolitical barrier)

Geopolitical complexity creates significant barriers for an energy-importing county, such as Bangladesh. Insufficient regional cooperation, possible tariff fluctuations and existing contractual limitations has impeded cross-border electricity trade, such as importing clean power from Nepal and Bhutan through India (Haque, Dhakal and Mostafa, 2020; Zaman and Brudermann, 2018).

Box 2. List of barriers relevant to Bangladesh in accelerating energy efficiency improvement

1. Shortage of trained manpower with right skills (human capacity barrier)

Shortage of skilled manpower, technical experts, professionally trained personnel in the industry and financial sectors, for conducting research and development and energy audits and effective energy management, among others (Haque, 2014; Hasan and others, 2019b; Islam and others, 2014).

2. Functional limitation (institutional barriers)

Complexity of collaboration among different energy-related public organizations. Complex bureaucratic system makes the situation worse and cannot influence energy management practices. Association of energy service companies with the relevant industries is very limited (Haque, 2014; Hasan and others, 2019b; Islam and others, 2014).

3. Absence of appropriate regulations (policy and governance barrier)

Lack of adequate regulations covering energy efficiency standards, implementation, financing, pricing, energy management practice and energy audits limits efforts to improve energy efficiency in Bangladesh. Moreover, unfavourable policies impose additional taxes and duties on energy-saving technologies and equipment (Haque, 2014; Hasan and others, 2019a, Hasan, 2019a; Hossain, Sarkar and Pargal, 2017; Islam and others, 2014; Hartley-Lewis and Islam, 2018).

4. Limited research and development and demonstration (technical barrier)

Technological uncertainty, very few research and development activities and limited technological demonstration of energy efficiency (Hasan and others, 2019a; Hasan and others, 2019b; Islam and others, 2014).

5. Limited capital and few private investments (economic and financial barrier 1)

Limited access to finance, high initial cost and difficulties in attracting attract private investment for energy efficiency projects are vital barriers (Haque, 2014; Islam and others, 2014).

6. Unfavourable energy price and future uncertainties (economic and financial barrier 2)

The current low price of energy does not encourage energy savings through energy efficiency measures. In addition, the complexity of non-uniform energy pricing, limited financial incentives and unpredictable future energy prices make it more difficult to implement such measures (Hasan and others, 2019a; Hasan and others, 2019b; Hossain, Sarkar and Pargal, 2017; Islam and others, 2014).

7. Investment preference for production over efficiency: (economic and financial barrier 3)

The preference of investors for production over energy efficiency projects is a barrier to promoting energy efficiency (Hasan and others, 2019a; Hossain, Sarkar and Pargal, 2019; Hasan and others, 2019b; Islam and others, 2014).

8. Lack of technological benchmarks, cost-benefit analysis and other relevant information: (informational barriers 1)

Absence of data collection and poor quality of the information about cost-benefits analysis, technological benchmarks, energy expenditure, opportunities regarding energy efficiency are significant barriers that are limiting efforts to improve energy efficiency (Hasan and others, 2019a; Hasan and others, 2019b; Islam and others, 2014).

9. Lack of awareness (informational barrier 2)

End users, financiers and industrialists are not sufficiently aware of the benefits of energy efficient technologies (Haque, 2014; Hasan and others, 2019a; Hasan and others, 2019b; Hossain, Sarker and Pargal, 2017; Islam and others, 2014).

III. RESULTS AND DISCUSSION

3.1 Barriers to modern energy access: interpretive structural modeling analysis

The findings of a step-by-step ISM analysis are presented in sections 3.1.1 to 3.1.5.

3.1.1 SSIM: structural self-interaction matrix.

The structural self-interaction matrix for modern energy access barriers is presented in table 2. ISIM is built using four types of barrier to barrier pairwise relations (1 through 14) using symbols V,A,X and O.

Table 2. Structural self-interaction matrix for modern energy access barriers

Barriers	14	13	12	11	10	9	8	7	6	5	4	3	2
1	V	O	O	V	O	O	O	V	V	O	O	O	A
2	O	O	O	V	O	O	O	O	V	O	O	A	
3	V	O	V	V	O	V	O	O	O	V	O		
4	O	O	O	O	O	V	O	V	V	V			

Table 2. *(continued)*

Barriers	14	13	12	11	10	9	8	7	6	5	4	3	2
5	O	A	O	V	V	V	V	V	V				
6	A	A	A	V	A	A	O	A					
7	O	A	V	V	A	A	O						
8	O	O	O	O	O	O							
9	O	A	V	V	V								
10	O	A	O	V									
11	A	O	A										
12	A	O											
13	V												

For example, in the SSIM table 2, cell (1,14) is denoted by V because barrier 1 aids in the elimination of barrier 14; cell (1,2) is denoted by A because barrier 1 aids in the abatement of barrier 2; and cell (2,14) is denoted by O because barrier 2 and 14 are unrelated. As there is no barrier pair that helps to alleviate each other, the cell is indicated by X.

3.1.2 Reachability matrix.

Following the rules in table 3, the SSIM in table 2 is converted into the initial reachability matrix by replacing symbols V, A, X, and O with 0 and 1. Table 4 shows the resulting initial reachability matrix.

Table 3. Rules to follow in deriving reachability matrix from the structural self-interaction matrix

Sl. No.	Symbol of (i, j) Cell in SSIM	Substituted in initial reachability matrix	
		Cell (i, j)	Cell (j, i)
1	V	1	0
2	A	0	1
3	X	1	1
4	O	0	0

Source: Table compiled for the purpose of this study using information available from published literature (Ansari and others, 2013).

Table 4. Initial reachability matrix for modern energy access barriers

Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	0	0	0	0	1	1	0	0	0	1	0	0	1
2	1	1	0	0	0	1	0	0	0	0	1	0	0	0
3	0	1	1	0	1	0	0	0	1	0	1	1	0	1
4	0	0	0	1	1	1	1	0	1	0	0	0	0	0
5	0	0	0	0	1	1	1	1	1	1	1	0	0	0
6	0	0	0	0	0	1	0	0	0	0	1	0	0	0
7	0	0	0	0	0	1	1	0	0	0	1	1	0	0
8	0	0	0	0	0	0	0	1	0	0	0	0	0	0
9	0	0	0	0	0	1	1	0	1	1	1	1	0	0
10	0	0	0	0	0	1	1	0	0	1	1	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0
12	0	0	0	0	0	1	0	0	0	0	1	1	0	0
13	0	0	0	0	1	1	1	0	1	1	0	0	1	1
14	0	0	0	0	0	1	0	0	0	0	1	1	0	1

While the initial reachability matrix is based on direct links, the final reachability matrix incorporates indirect linkages through the use of the transitivity criteria, as indicated in step 3 of the ISM method discussed in section 2. The results show 17 indirect links after conducting first-order transitivity checks, and one additional indirect link after carrying out second- and third-order transitivity checks. For example, if barrier 2 is resolved/reduced, it aids in the mitigation of barrier 1, and barrier 1 aids in the reduction of barrier 14. As a result, overcoming barrier 2 significantly contributes towards the reduction of barrier 14. The resulting final reachability matrix is shown in table 5. In the final reachability matrix, the driving power is determined by counting and adding 1 in each of the barrier's rows, and the dependence is computed by counting and adding 1 in each of the barrier's column.

Table 5. Final reachability matrix for modern energy access barriers

Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Driving Power
1	1	0	0	0	0	1	1	0	0	0	1	1	0	1	6
2	1	1	0	0	0	1	1	0	0	0	1	1	0	1	7
3	1	1	1	0	1	1	1	1	1	1	1	1	0	1	12

Table 5. *(continued)*

Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Driving Power
4	0	0	0	1	1	1	1	1	1	1	1	1	0	0	9
5	0	0	0	0	1	1	1	1	1	1	1	1	0	0	8
6	0	0	0	0	0	1	0	0	0	0	1	0	0	0	2
7	0	0	0	0	0	1	1	0	0	0	1	1	0	0	4
8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
9	0	0	0	0	0	1	1	0	1	1	1	1	0	0	6
10	0	0	0	0	0	1	1	0	0	1	1	1	0	0	5
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
12	0	0	0	0	0	1	0	0	0	0	1	1	0	0	3
13	0	0	0	0	1	1	1	1	1	1	1	1	1	1	10
14	0	0	0	0	0	1	0	0	0	0	1	1	0	1	4
Dependence power	3	2	1	1	4	12	9	5	5	6	13	11	1	5	

3.1.3 Level partitioning.

From the reachability matrix, the reachability set and antecedent set for each of the barriers under consideration can be determined, followed by the intersection of the reachability set and antecedent set for each barrier. Barriers 8 and 11 are positioned in level I in the case of modern energy access barriers because they have the same element in the reachability set and intersection set (table 6). In the second iteration (table 7), these two barriers are omitted. This method is continued until all of the barrier levels are determined; the findings are presented in tables 8 to 12.

Table 6. Level partitioning of modern energy access barriers: stage 1

Elements	Reachability	Antecedent	Intersection	Level
1	1,6,7,11,12,14	1,2,3	1	
2	1,2,6,7,11,12,14	2,3	2	
3	1,2,3,5,6,7,8,9,10,11,12,14	3	3	
4	4,5,6,7,8,9,10,11,12	4	4	
5	5,6,7,8,9,10,11,12	3,4,5,13	5	
6	6,11	1,2,3,4,5,6,7,9,10,12,13,14	6	

Table 6. *(continued)*

Elements	Reachability	Antecedent	Intersection	Level
7	6,7,11,12	1,2,3,4,5,7,9,10,13	7	
8	8	3,4,5,8,13	8	I
9	6,7,9,10,11,12	3,4,5,9,13	9	
10	6,7,10,11,12	3,4,5,9,10,13	10	
11	11	1,2,3,4,5,6,7,9,10,11,12,13,14	11	I
12	6,11,12	1,2,3,4,5,7,9,10,12,13,14	12	
13	5,6,7,8,9,10,11,12,13,14	13	13	
14	6,11,12,14	1,2,3,13,14	14	

Table 7. Level partitioning of energy access barriers: stage 2

Elements	Reachability	Antecedent	Intersection	Level
1	1,6,7,12,14	1,2,3	1	
2	1,2,6,7,12,14	2,3	2	
3	1,2,3,5,6,7,9,10,12,14	3	3	
4	4,5,6,7,9,10,12	4	4	
5	5,6,7,9,10,12	3,4,5,13	5	
6	6	1,2,3,4,5,6,7,9,10,12,13,14	6	II
7	6,7,12	1,2,3,4,5,7,9,10,13	7	
9	6,7,9,10,12	3,4,5,9,13	9	
10	6,7,10,12	3,4,5,9,10,13	10	
12	6,12	1,2,3,4,5,7,9,10,12,13,14	12	
13	5,6,7,9,10,12,13,14	13	13	
14	6,12,14	1,2,3,13,14	14	

Table 8. Level partitioning of modern energy access barriers: stage 3

Elements	Reachability	Antecedent	Intersection	Level
1	1,7,12,14	1,2,3	1	
2	1,2,7,12,14	2,3	2	
3	1,2,3,5,7,9,10,12,14	3	3	
4	4,5,7,9,10,12	4	4	
5	5,7,9,10,12	3,4,5,13	5	
7	7,12	1,2,3,4,5,7,9,10,13	7	
9	7,9,10,12	3,4,5,9,13	9	
10	7,10,12	3,4,5,9,10,13	10	
12	12	1,2,3,4,5,7,9,10,12,13,14	12	III
13	5,7,9,10,12,13,14	13	13	
14	12,14	1,2,3,13,14	14	

Table 9. Level partitioning of modern energy access barriers: stage 4

Elements	Reachability	Antecedent	Intersection	Level
1	1,7,14	1,2,3	1	
2	1,2,7,14	2,3	2	
3	1,2,3,5,7,9,10,14	3	3	
4	4,5,7,9,10	4	4	
5	5,7,9,10	3,4,5,13	5	
7	7	1,2,3,4,5,7,9,10,13	7	IV
9	7,9,10	3,4,5,9,13	9	
10	7,10	3,4,5,9,10,13	10	
13	5,7,9,10,13,14	13	13	
14	14	1,2,3,13,14	14	IV

Table 10. Level partitioning of modern energy access barriers: stage 5

Elements	Reachability	Antecedent	Intersection	Level
1	1	1,2,3	1	V
2	1,2	2,3	2	
3	1,2,3,5,9,10	3	3	
4	4,5,9,10	4	4	
5	5,9,10	3,4,5,13	5	
9	9,10	3,4,5,9,13	9	
10	10	3,4,5,9,10,13	10	V
13	5,9,10,13	13	13	

Table 11. Level partitioning of modern energy access barriers: stage 6

Elements	Reachability	Antecedent	Intersection	Level
2	2	2,3	2	VI
3	2,3,5,9	3	3	
4	4,5,9	4	4	
5	5,9	3,4,5,13	5	
9	9	3,4,5,9,13	9	VI
13	5,9,13	13	13	

Table 12. Level partitioning of modern energy access barriers: stage 7

Elements	Reachability	Antecedent	Intersection	Level
3	3,5	3	3	VIII
4	4,5	4	4	VIII
5	5	3,4,5,13	5	VII
13	5,13	13	13	VIII

The level partitioning technique entails creating eight levels of hierarchy for the 14 barriers. The top ones in hierarchy are barriers 8 and 11 while barriers 3, 4, and

13 are at the bottom. As a bottom-level barrier has the greatest influence on all other barriers in the hierarchy above it, the barriers at level VIII in the analysis (barrier #3 – unfavourable political environment; barrier #4 – top-down policymaking, barrier #13 – limited disclosure and inaccurate information) require the most attention and highest priority in order to overcome all other barriers and accelerate modern energy access in Bangladesh. On the other hand, the top-level barriers (barrier #8 – safety and efficiency; and barrier #11 – high cost of grid power and increasing cost of doing business) do not affect the other barriers positioned in the lower-levels.

3.1.4 Barrier hierarchy.

Hierarchy of the ISM hierarchy model is built by utilizing the level partitioning and final reachability matrix (figure 2), top-level barriers, #8 –safety and efficiency, and #11 – high cost of grid power and increasing cost of doing business, and the bottom level (level VIII) barriers. #3 – unfavourable political environment, #4 – top-down policymaking, and #13 – limited disclosure and inaccurate information. Between the top and bottom levels, there are institutional, geopolitical, informational, resource, and environmental barriers in the ISM hierarchy.

3.1.5 The cross-impact matrix multiplication analysis.

MICMAC analysis is used to classify the barriers into four groups, namely autonomous, independent, linkage and dependent. There is no linkage barrier. The dependent barriers are #6 (unreliable grid power supply: technical barrier 1), #7 (exploration and infrastructural limitation for primary energy supply: technical barrier 2), #11 (high cost of grid power and increasing cost of doing business: economic and finance barrier 3), and #12 (depleting local gas reserve and future greenhouse emission rise: resource and environment barrier), which appear in the upper section of the ISM hierarchy. They are affected by the four independent barriers: #3 (unfavourable political environment: policy and governance barrier 1), #4 (top-down policymaking: policy and governance barrier 2), #5 (Inefficient policy: policy and governance barrier 2), and #13 (limited disclosure and inaccurate information: informational barrier 1). These independent barriers are the most important and are at the bottom of the ISM hierarchy. Barriers #1 (inefficiency, complexity and unbalance evaluation of value chain: institutional barrier 1), #2 (corruption: institutional barrier 2), #8 (safety and efficiency: technical barrier 3), #9 (inappropriate subsidy allocation and lack of appropriate tariff policy: economic and finance barrier 1), #10 (inefficient financing and donor dependent policy: economic and finance barrier 2), #14 (limited cooperation and transactional complexity: geopolitical barrier), are autonomous barriers that have limited interaction with other barriers and are in the middle of the ISM hierarchy. The results from the cross-impact matrix multiplication applied to classification analysis, the distribution of barriers by various typology, for energy access barriers are shown in figure 3.

Figure 2. Interpretive structure modelling framework for modern energy access barriers

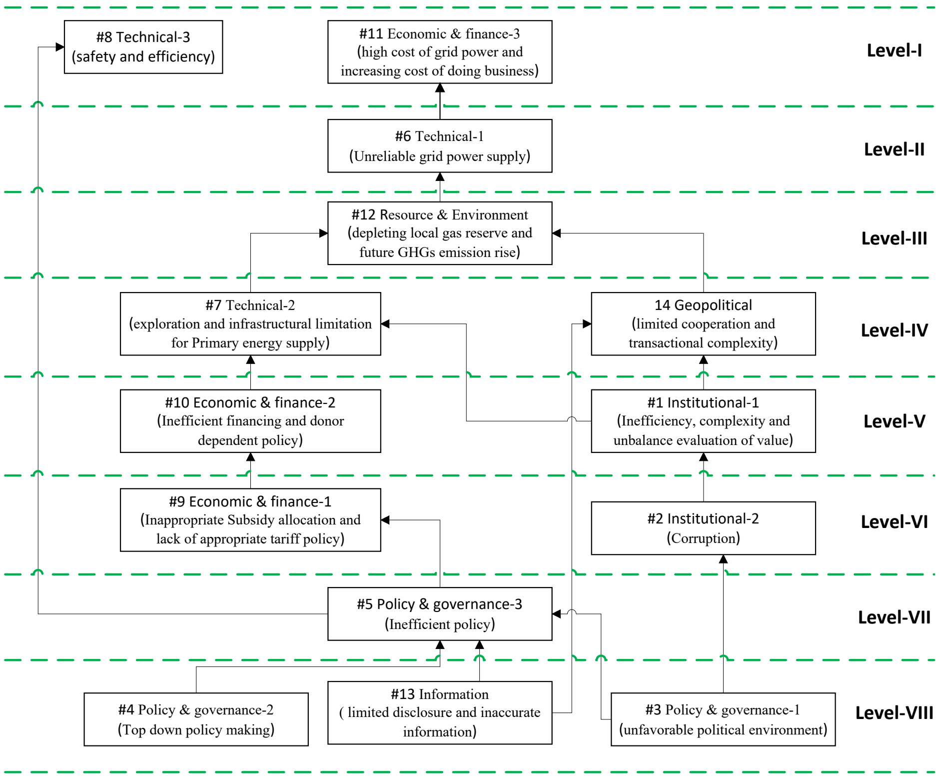
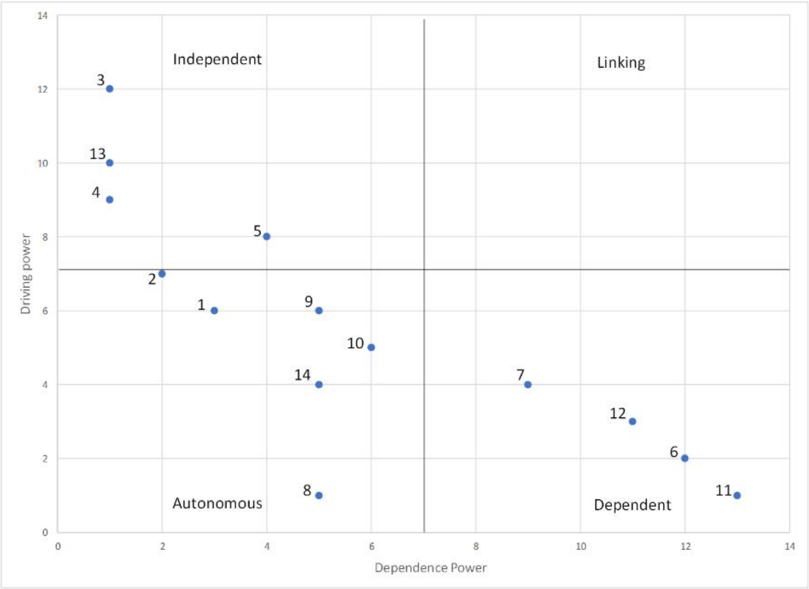


Figure 3. Barriers with varying driving and dependence power from cross-impact matrix multiplication applied to classification analysis



3.2 Interpretive structural modeling analysis for energy efficiency improvement barriers

The analysis and the findings for energy efficiency barriers are illustrated in sections 3.2.1 to

3.2.1 Structural self-interaction matrix.

SSIM for energy efficiency barrier are shown in table 13, in which four symbols V, A, O and X ,are used to represent the pairwise conceptual relationship between the barriers.

Table 13. Structural self-interaction matrix for renewable energy penetration barriers

Barriers	9	8	7	6	5	4	3	2
1	O	V	O	O	O	V	V	V
2	O	A	O	O	V	O	A	
3	O	A	V	V	V	O		

Table 13. *(continued)*

Barriers	9	8	7	6	5	4	3	2
4	O	O	V	O	V			
5	A	A	A	A				
6	O	O	V					
7	A	A						
8	V							

3.2.2 Reachability matrix.

Y replacing the symbols V, A, X and O with 0 and 1, SSIM in table 13 is converted into an initial reachability matrix shown, as shown in table 14.

The indirect linkages are incorporated in the final reachability matrix through transitivity tests using the transitivity criterion, as described in step 3 of the ISM approach in section 2. After completing first- and second-order transitivity tests, five indirect connections among energy efficiency barriers are discovered, which are incorporated into the final reachability matrix, shown in table 15. As an example of an indirect link, barrier 8 affects barrier 3, and barrier 3 influences barrier 6, therefore, barrier 8 indirectly influences barrier 6. As a result, cell (8, 6) which is represented by 0 in the initial reachability matrix (table 14) is substituted by 1 in the final reachability matrix (table 15). From the final reachability matrix, the driving power of a barrier is determined by counting and adding 1 in the corresponding rows, whereas dependency is measured by tallying and adding 1 in the column of the barrier (table 15).

Table 14. Initial reachability matrix for energy efficiency improvement barriers

Barriers	1	2	3	4	5	6	7	8	9
1	1	1	1	1	0	0	0	1	0
2	0	1	0	0	1	0	0	0	0
3	0	1	1	0	1	1	1	0	0
4	0	0	0	1	1	0	1	0	0
5	0	0	0	0	1	0	0	0	0
6	0	0	0	0	1	1	1	0	0
7	0	0	0	0	1	0	1	0	0
8	0	1	1	0	1	0	1	1	1
9	0	0	0	0	1	0	1	0	1

Table 15. Final reachability matrix for energy efficiency improvement barriers

Barriers	1	2	3	4	5	6	7	8	9	Driving power
1	1	1	1	1	1	1	1	1	1	9
2	0	1	0	0	1	0	0	0	0	2
3	0	1	1	0	1	1	1	0	0	5
4	0	0	0	1	1	0	1	0	0	3
5	0	0	0	0	1	0	0	0	0	1
6	0	0	0	0	1	1	1	0	0	3
7	0	0	0	0	1	0	1	0	0	2
8	0	1	1	0	1	1	1	1	1	7
9	0	0	0	0	1	0	1	0	1	3
Dependence power	1	4	3	2	9	4	7	2	3	

3.2.3 Level partitioning gives the relative importance of the barriers. In this analysis, barrier 5 is assessed as level I barriers from the first stage iteration (table 16) and is omitted in the subsequent iterations. In this approach six hierarchy levels of barriers are identified; the findings are presented in tables 17 to 19.

Table 16. Level partitioning of energy efficiency improvement barriers: stage 1

Elements	Reachability	Antecedent	Intersection	Level
1	1,2,3,4,5,6,7,8,9	1	1	
2	2,5	1,2,3,8	2	
3	2,3,5,6,7	1,3,8	3	
4	4,5,7	1,4	4	
5	5	1,2,3,4,5,6,7,8,9	5	I
6	5,6,7	1,3,6,8	6	
7	5,7	1,3,4,6,7,8,9	7	
8	2,3,5,6,7,8,9	1,8	8	
9	5,7,9	1,8,9	9	

Table 17. Level partitioning of energy efficiency improvement barriers: stage 2

Elements	Reachability	Antecedent	Intersection	Level
1	1,2,3,4,6,7,8,9	1	1	
2	2	1,2,3,8	2	II
3	2,3,6,7	1,3,8	3	
4	4,7	1,4	4	
6	6,7	1,3,6,8	6	
7	7	1,3,4,6,7,8,9	7	II
8	2,3,6,7,8,9	1,8	8	
9	7,9	1,8,9	9	

Table 18. Level partitioning of energy efficiency improvement barriers: stage 3

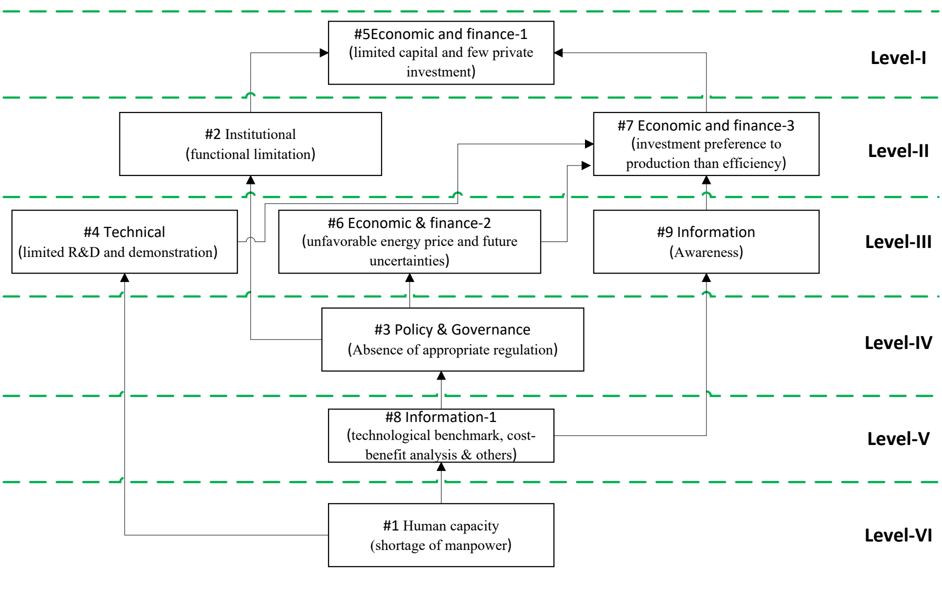
Elements	Reachability	Antecedent	Intersection	Level
1	1,3,4,6,8,9	1	1	
3	3,6	1,3,8	3	
4	4	1,4	4	III
6	6	1,3,6,8	6	III
8	3,6,8,9	1,8	8	
9	9	1,8,9	9	III

Table 19. Level partitioning of Energy Efficiency Improvement Barriers: stage 4

Elements	Reachability	Antecedent	Intersection	Level
1	1,3,8	1	1	VI
3	3	1,3,8	3	IV
8	3,8	1,8	8	V

3.2.4 Barrier hierarchy: The barriers are positioned in the hierarchy diagram according to their hierarchy level estimated in section 3.2.3. The arrows show the direction of interaction between two barriers. Figure 4 depicts the established ISM model for energy efficiency improvement barriers in Bangladesh; #5 (limited capital and few private investments; economic and financial barrier 1) is at the top level (level 1) and #1 (shortage of manpower: human capacity barrier) is at the bottom level (level VI). Between the top and lowest levels, are the technical, policy and governance, informational, institutional, and resource and environment barriers.

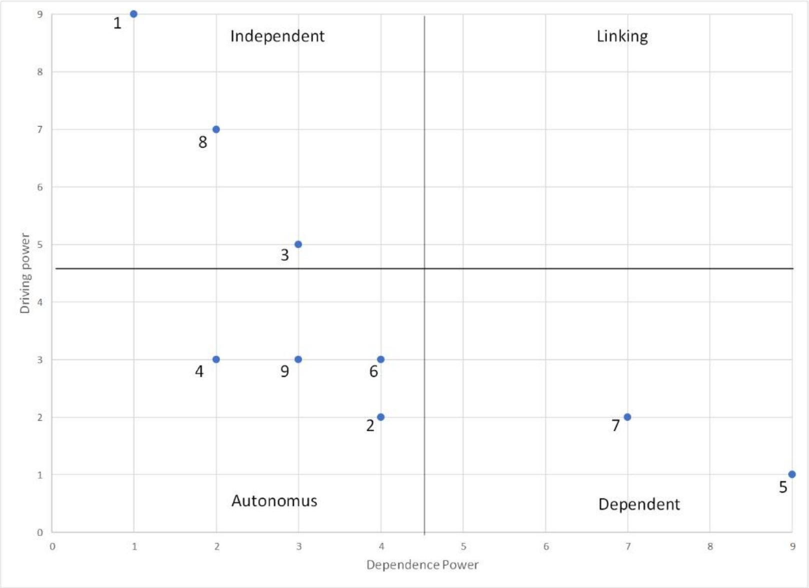
Figure 4. Interpretive structural modelling model framework for energy efficiency barriers



3.2.5 Cross-impact matrix multiplication applied to classification analysis: three independent, four autonomous and two dependent barriers are identified. Barriers #1 (shortage of manpower: human capacity barrier), #3 (absence of appropriate regulation: policy and governance barrier), and #8 (limited technological benchmark, cost-benefit analysis, and others: information 1) are independent barriers set in the lower portion of the ISM hierarchy. These are the most important barriers and have a significant impact on the dependent barriers: #5 (limited capital and few private investments: economic and finance barrier 1) and #7 (investment preference for production over efficiency: economic and finance barrier 3), which are at the upper part of the ISM hierarchy. Barriers #2 (functional limitation: institutional barrier),

#4 (limited research and development and demonstration: technical barrier 2), #6 (unfavourable energy price and future uncertainties: economic and finance barrier 2), and #9 (lack of awareness: information barrier 2), on the other hand, are autonomous barriers that have limited interaction with other barriers and are at the between the top and bottom levels of the ISM hierarchy. Figure 5 depicts the MICMAC results with their corresponding classifications.

Figure 5. Barriers with varying driving and dependence power indicated by the cross-impact matrix multiplication applied to classification analysis



Based on the ISM study on modern energy access barriers (figure 2), the most significant barriers for enhancing modern energy access are top-down policy formulation (#4), adverse political conditions (#3), and limited disclosure and inaccurate information (#13). As a result, the policy may become inefficient and ineffective (# 5). In the MICMAC study, they were identified as driving barriers (figure 3), which shows how the combined influence of these four barriers influence the other barriers, such as inappropriate tariff policy and subsidy allocation (#9), institutional inefficiency (#1), limited financing (#10), and exploration and infrastructure limitations in primary energy supply (#7). The end result is inconsistent grid power supply (#6) and high grid power costs (#11), which limit access to modern energy in Bangladesh.

Based on an ISM analysis, the major impediment to improving energy efficiency in Bangladesh is lack of skilled labour (figure 4). Aside from human capacity limitations (#1), based on the MICMAC analysis (figure 5), two other driving barriers were lack of suitable regulations (#3) and technical benchmark, cost-benefit analysis, and other relevant information limitations (#8). The collective impact of these three driving barriers exacerbates additional barriers, such as insufficient research and development (#4), institutional functional complexity (#2), unfavourable pricing (#6) and limited awareness (#9). The final barrier is lack of financial capital and low private investments (#5) and a bias towards investment in energy supply enhancement reflecting the preference for investing in gross output increase rather than in efficiency enhancement in the production process (#7), which limits efforts to improve overall energy efficiency in Bangladesh.

IV. CONCLUSION

This study makes an important contribution by presenting a comprehensive list of factors that act as barriers to accelerating improvements in energy efficiency and access to modern energy in Bangladesh. An analysis is conducted using an ISM framework and the cross-impact matrix multiplication applied to classification approach to find out how the barriers can be overcome by addressing them independently and/or in clusters/packages. While human capacity-building can be prioritized independently to enhance energy efficiency, to address energy access, lack of information, political interference, top down policy practices need to be considered together to overcome the barriers]. For this study, published literature is used to identify fourteen distinct barriers to modern energy access, and nine distinct barriers for improvement in energy efficiency in the context of Bangladesh. However, the systematic analysis helps in concluding that all fourteen barriers to modern energy access, and nine barriers for improvement in energy efficiency can be considered as interlinked systems in which no single barrier can be ignored. To remove barriers, a big push needs to come from strategic actions through regulations, more implementation of comprehensive energy policies that reflects the government’s commitment to address multiple barriers and an incentive design for private sector investment. A whole policy portfolio with a strategic mix and sequencing of interlinked policies are necessary without losing sight of any one of the barriers.

Policy to advance progress in energy efficiency in Bangladesh cannot ignore factors, such as , the shortage of manpower and the need for research and development and energy auditing and energy management,. If long-term policies were to be put in place to regulate energy efficiency standards in various sectors, financing and energy management practices and energy audits would follow, but institutional arrangements could emerge through policy and regulations, as has been experienced in many other countries. Unfavourable conditions, such as additional taxes and duties on energy-saving technologies and equipment and limited information about cost-benefits analysis for energy efficiency improvement programmes and projects, and the development of a technological benchmark for energy efficiency improvement must be addressed immediately. Actions to address these factors would contribute towards tackling other barriers, such as the preference of investors for energy production projects over energy efficiency projects, limited capital and few private investments. Under a systems approach, to address the identified barriers, their interconnections and the nature of mutual interdependence must be considered. Barrier analysis suggests that limited research and development activities and limited technological demonstration of energy efficiency also need appropriate attention from line ministries, such as those responsible for industry, buildings, transport and relevant departments and not only the power and energy ministries. Simultaneously, focus should be placed on low electricity prices, which reduces motivation for change from end users, limited financial incentives and unpredictable energy prices, as they make it more difficult to implement energy efficiency measures. Institutional arrangements need to be in place to generate information and create awareness among end users, financiers and industrialists about the benefits of energy-efficient technologies. Institutional inefficiency, such as complexity of collaboration, poor association with energy service companies and lack of influence in energy management practices also need to be addressed by the government.

To achieve 24/7 access to modern energy services, the most important actions are to develop an accurate database for providing reliable demand estimates and encourage disclosures; create a political atmosphere with minimized intervention and long-term policy certainty; reform the highly centralized non-transparent bureaucratic system of policymaking under which constructive stakeholder's participation is absent; scrap inefficient policies, such as the continuation of power generation from an ad hoc policy favouring high-cost and inefficient quick rental power plants or captive power generation; and communicate a clear policy message to reconcile power sector development and climate change mitigation targets. Sequentially, such actions would help to overcome such barriers, such as limited exploration and infrastructure related to primary energy, inability to offer affordable and reliable grid power due to costlier petroleum and LNG imports, increased use of costly liquid fuel-based generation, and more emission intensive oil-based power generation. Six autonomous barriers also deserve equal attention: (1) institutional inefficiency,. such as delayed policy implementation, lack of coordination between generation, transmission and distribution; (2) the complex administrative environment and institutional corruption, such as illegal supply connection of gas and electricity, and bribes to tamper meters in urban areas; (3) inappropriate tariff policies, such as irrational energy subsidies and inefficient pricing structure and the absence of long-term energy tariff plans and market-based tariffs; (4) donor-dependent financing and policy formulation for the energy sector, which results in investment preferencing power generation over transmission and distribution; (5) the lingering problem caused by the low technical efficiency of the grid connected power plants; and (6) inadequate regional cooperation, such as the preference for bilateral policy rather than regional policy, the absence of open market concepts, geopolitical issues and few successes in cross-border electricity trade.

In summary, the analysis shows that the barriers can be overcome through various targeted policy and regulatory mechanisms. By making room for new institutional arrangements and the strategic role of local experts, stakeholders, such as manufacturers, businesses and users can create a sociopolitical environment that makes it possible to break the current interlinked chain of barriers. Simultaneous supplementary efforts, such as provision of capacity-building, creation of a database for both the demand and supply sides and improvement in coordination across institutions, could also be highly beneficial.

Acknowledgement and funding

The authors acknowledge the support of Bangabandhu chair endowment (2018-2022 July) of the Ministry of Foreign Affairs, of the Government of Bangladesh) at the Asian Institute of Technology, Thailand for a major part of the work which they started as Bangabandhu Chair Researcher and Bangabandhu Chair Professor. The endowment was provided to conduct research primarily on the energy sector of Bangladesh. The authors also acknowledge the funding under EDIT-AIT project for extending the initial work to achieve the final outcome s of this paper. Energy Demand changes Induced by Technological and Social innovations (EDITS) project is part of the initiative coordinated by the Research Institute of Innovative Technology for the Earth (RITE) and International Institute for Applied Systems Analysis (IIASA) (and funded by Ministry of Economy, Trade, and Industry (METI), Japan).

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