Justification of Solar Home System in Rural Bangladesh Based on Risk Indicators: An Integrated Multi-Criteria Decision Making Approach

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Abstract- In this study, the use of Solar Home Systems (SHS) in rural regions of Bangladesh is justified and compared to different renewable energy technologies (RETs).Various risk indicators of SHS, Solar-Diesel Hybrid Mini-grid, Biogas Plant and Wind Turbine are analysed and then ranked. An integrated Best Worst Method (BWM) and weighted aggregated sum product assessment (WASPAS) method is proposed to select the best renewable energy technology based on risk indicators. At first, nine (9) risk indicators were selected based on literature review and experts' opinion. Then, BWM was deployed to find the weights of the risk indicators. Finally, a Multi-criteria decision making (MCDM) method, named WASPAS, was applied to select the optimum renewable energy technology for the study area. The results revealed that the SHS is the best technology. Furthermore, a sensitivity analysis was carried out to check the consistency of the rank order. The outcome of this study and the decision model might be applicable to other isolated areas in the country as well as other developing countries.

Keywords-BWM, WASPAS, SHS, Renewable Energy Technology

1. Introduction

In developing countries like Bangladesh, the bulk of electricity is generated from fossil fuels (coal, oil, and natural gas). Fossil fuel based traditional power generation is harmful to the environment because of greenhouse gas emissions. Many environmental organizations have made their concern about the harmfulness of conventional power generation. Recently, some of the organizations have protested against a newly planned coal-based power generation in the country [1].

The increasing need for electricity, in Bangladesh, cannot be met with the remaining reserve of coal, oil, and gas; these fuel sources will deplete soon. New energy sources are required to be explored and included in the energy mix of the country. Besides the energy crisis, centralized generation units do not have the capability and infrastructure to reach remote areas. Thus, many villages are still not electrified. Sustainable development is hindered due to inaccessibility of electricity. Initiatives are required in those areas where the main grid cannot reach shortly. Decentralized generation using renewable energy sources can be a viable option considering the energy need, depletion and high price of fossil fuels, and environmental issues. Dan M. Ionel claims that wind and solar concentrated power plants with integrated energy storage are expected to be major contributors to clean energy generation [2].

There are a huge number of off-grid villages in Bangladesh. Most off-grid villages are islands or char lands. Owing to the remoteness of these locations, electricity from main grid is not reachable. Therefore, a lot of villagers of these areas use Kerosene as lighting fuel. This fuel emits black carbon during combustion which increases Green House Gas (GHG) and harm the environment seriously. The proposed study area, Kalur Para, is not exception in this regard. However, due to the awareness program of government and non-government organizations and extensive use of Solar Home System (SHS), people in the village use Kerosene rarely.

The SHS not only electrify the households, but also playing an important role, both economically and socially, in the village. Moreover, it has environmental advantages. Hoque and Das [3] showed that Bangladesh can reduce 11,604 kg CO_2 in 20 years by using SHS. Another research also shows that emissions could be significantly reduced with the use of roof-top PV systems for charging electric vehicles [4]. However, rapid developments of various types of renewable energy technologies make SHS competitive in the market. Therefore, there will be risk in future whether SHS sustain in the study area. In this regard, a study is required to analyse the risk indicators of different renewable energy technologies and compare it with the SHS to verify whether the technology is the most risk free and feasible for the Kalur Para village. In this study, three (3) types of renewable energy technologies are selected (except SHS) for the analysis. These technologies are Solar-Diesel Hybrid Mini-grid, Biogas Plant and Wind Turbine. The assessment is done based on BWM-WASPAS integrated MCDM method. BWM is a new MCDM method to calculate the subjective weights using the best-worst criteria and the method is also well consistent than Analytic Hierarchy Process (AHP) [5]. Due to the better performance than AHP, BWM is selected for the study. The WASPAS method is a combination of weighted sum model (WSM) and weighted product model (WPM), where WASPAS gives more accurate results than WSM and WPM [6]. It is evident that a few researches were done regarding the selection of renewable energy technologies using BWM and WASPAS method. However, during literature review, none of the researches were found directly related to renewable energy technology selection and BWM. Yazdani et al. [7] proposed a hybrid D-ANP model for the comparative assessment and ranking of renewable energy technologies which combines ANP, WASPAS and COPRAS based on the DEMATEL technique. However, this model is applicable for the European countries and not for developing countries; this model also didn't use BWM. To the best of our knowledge, none of the researchers used integrated BWM-WASPAS model to analyse renewable energy technology selection. Moreover, the application of the proposed decision model for the study area is a novel idea. The main objectives of this study are given below.

- To construct a decision model based on integrated BWM-WASPAS model.
- To establish the risk indicators based on the local perspective.
- To calculate the weights of the risk indicators using BWM and import the weights to WASPAS method to obtain the final ranking of the renewable energy technologies.
- To perform sensitivity analysis varying the values of λ to check the consistency of the ranking order.

2. Methodology

The proposed decision framework is demonstrated in figure 1.

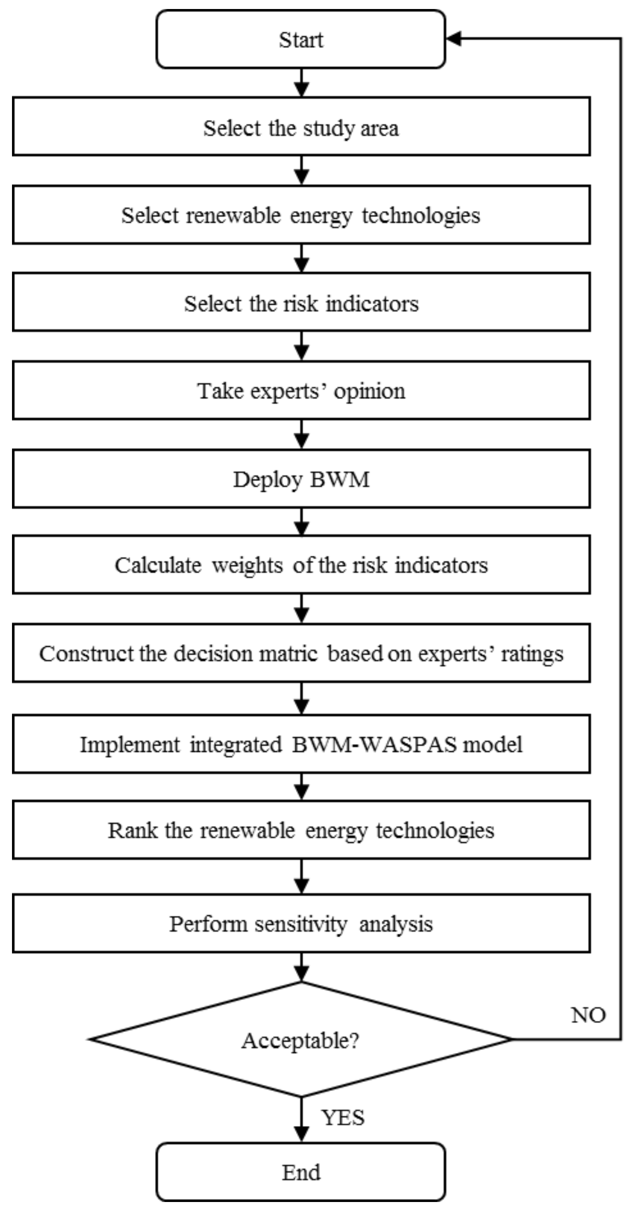

Figure 1. Proposed decision framework

Initially, four renewable energy technologies were selected based on the feasibility in the study area. Then, nine (9) risk indicators were selected after the literature survey and consulting with experts. These indicators were rated by experts and using BWM weights were obtained. To form the decision matrix, total eight (8) experts were selected from different government, non-government and academic organizations, with each having at least 10 years' experience in power and energy sector. The survey was carried out by email and telephone interview. A five (5) point Likert Scale was used to conduct the survey. After that, WASPAS model was applied to find out the rank order. A BMW-WASPAS integrated Matlab program was formulated to analyse the proposed framework. The decision matrix, types of criteria and weights of the risk indicators were used as input value. Finally, a sensitivity analysis was carried out by changing the values of λ.

2.1. Study Area

The chosen area for the case study is a remote village named Kalur Para which is surrounded by the Brahmaputra River. The village is located at the northern part of Bangladesh in Fulchari union Parishad of Fulchari Upazila (figure. 2) under the Gaibandha district of the Rangpur Division. According to the survey, the total area of the village is approximately 1.88 sq.km. Also, around 899 households and population size of 3510 is estimated. Therefore, the average household size is 3.90. The study area is a low-lying and flood-prone area. Agriculture is the most common occupation in this area. However, fishing is another competence occupation through which people conduct their life. The village is not connected by road and bridge with the Fulchari Upazila. So, boats are the only way of transportation for communication between the village and upazila. The inhabitants of the village have to travel at least 4-5 miles to a distant town in order to serve their daily purpose. Due to the disconnectedness of the village with the upazila and zila, this location is unique for the off-grid renewable energy system.

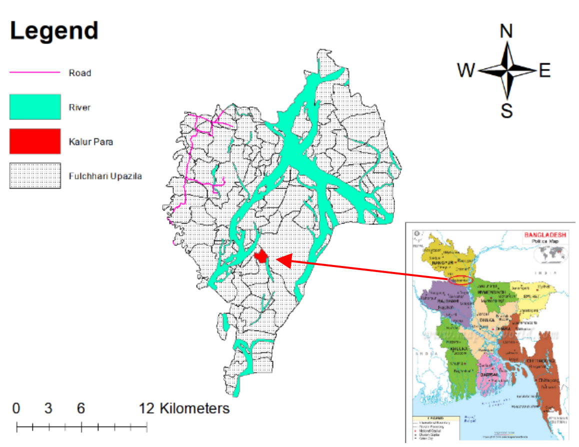

Figure 2.Map of Study Area

The village is out of national grid coverage, and near about 50% of households do not have access to electricity. About 45% of households use solar home system and rest of the 5% uses kerosene, candles for lighting, fuel-wood and cow-dung for cooking purposes.

2.2. Calculation of Best-Worst Method (BWM)

The following steps need to be followed to calculate the BWM.

Step 1: Determine the set of decision criteria. In this study, decision criteria are the risk indicators which are showed in table 1.

Table 1. Risk factors of renewable energy technologies

Risk Indicators	Definition	Reference
Force majeure risk (FMR)	Flood, cyclone, riverbank erosion, tsunami and storm surge.	[8]
Theft and vandalism (TV)	Copper wires, PV panels and other valuable materials or system components of the renewable energy systems could be stolen. Vandalism could happen when there is a conflict between the stakeholder and consumers.	[9]
Load uncertainty (LU)	Load forecasting and random load variation, poor estimation of load size which can cause unreliable power supply.	[10]
Geographical isolation (GI)	Teething troubles to purchase spare parts and repair the system components due to remoteness, shipping challenge and lack of skilled manpower in the study area.	[10]
Political instability (PI)	Sudden change of government due to coups, war and social conflict.	[11]
Inadequate business models	Effective business models could play an important role between stakeholders	[12]

(IBM)	and consumers.	
Environmental impact (EI)	Greenhouse gas emission, effect on ecosystem, noise.	[13]
Public resistance (PR)	Resistance of interest groups due to water supply, odour (biogas), noise, conflict with stakeholders, political incitement etc.	[14]
Stakeholder Management (SM)	Numerous parties involved whose activities between parties may cause negative result.	[10]

Step 2: Determine the best and worst criteria based on experts' preference. Best criterion means the most important criterion and worst criterion means the least important criterion. In this study, the best criterion is 'Force Majeure Risk' and worst criterion is 'Environmental Impact'.

Step 3: Determine the preference of the best criterion over all the criteria using numerical value between 1 and 9. The linguistic term of these values are given in Table 2.

Table 2. Scale of importance[15]

Numbers	Definition
1	Equal importance
2	Somewhat between Equal and Moderate
3	Moderately more important than
4	Somewhat between Moderate and Strong
5	Strongly more important than
6	Somewhat between Strong and Very strong
7	Very strongly important than
8	Somewhat between Very strong and Absolute
9	Absolutely more important than

Step 4: Determine the preference of all the criteria over the worst criterion using numerical value between 1 and 9.

Step 5: Estimate the optimal weights solving linear equations.

$$Min\ \xi_L$$

Subject to,

$$\left|w_b - a_{Bj}w_j\right| \leq \xi_L, for\ all\ j \quad (1)$$

$$\left|w_b - a_{jw}w_w\right| \leq \xi_L, for\ all\ j \quad (2)$$

$\sum w_j = 1; w_j \geq 0, for\ all\ j$

Considering Step3 and Step 4, followed by experts' judgement, equation (1) and (2) are solved. Then, following set of linear equations are formed which is demonstrated in table 3.

Table 3. Set of formulated linear equations

Considering the preference of the best criterion over other criteria	Considering preference of the other criteria over the worst criterion
$w_{FMR} - 1w_{FMR} \leq \xi_L$	$w_{TV} - 3w_{EI} \leq \xi_L$
$w_{FMR} - 6w_{TV} \leq \xi_L$	$w_{LU} - 4w_{EI} \leq \xi_L$
$w_{FMR} - 6w_{LU} \leq \xi_L$	$w_{IBM} - 5w_{EI} \leq \xi_L$
$w_{FMR} - 5w_{IBM} \leq \xi_L$	$w_{GI} - 7w_{EI} \leq \xi_L$
$w_{FMR} - 2w_{GI} \leq \xi_L$	$w_{SM} - 4w_{EI} \leq \xi_L$
$w_{FMR} - 8w_{SM} \leq \xi_L$	$w_{PI} - 7w_{EI} \leq \xi_L$
$w_{FMR} - 3w_{PI} \leq \xi_L$	$w_{PR} - 5w_{EI} \leq \xi_L$
$w_{FMR} - 7w_{EI} \leq \xi_L$	
$w_{FMR} - 3w_{PR} \leq \xi_L$	

$$w_{FMR} + w_{TV} + w_{LU}w_{IBM} + w_{GI} + w_{SM} + w_{PI} + w_{EI} + w_{PR} = 1$$

Where, $w_{FMR} \geq 0; w_{TV} \geq 0; w_{IBM} \geq 0;\ w_{GI} \geq 0; w_{SM} \geq$
$; w_{PI} \geq 0; w_{EI} \geq 0;\ w_{PR} \geq 0$

2.3. Calculation of weighted aggregated sum product assessment (WASPAS) Method

The following steps need to be followed to implement WASPAS method[6].

Step 1: Initialize the decision matrix for solving the decision problem.

$$X_{ij} = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \quad (3)$$

Where m is the number of alternatives, n is the number of assessment criteria and X_{ij} is the performance of i^{th} alternative with respect to j^{th} criterion.

Step 2: Normalize the decision matrix.

For beneficial criteria,

$$\bar{x}_{ij} = \frac{x_{ij}}{max_i x_{ij}} \quad (4)$$

For non-beneficial criteria,

$$\bar{x}_{ij} = \frac{min_i x_{ij}}{x_{ij}} \quad (5)$$

Where, $\bar{x}_{ij}$ is then normalized value ofx_{ij}.

Step 3: Estimate the total relative importance based on Weighted Sum Model (WSM).

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij}\, w_j \quad (6)$$

Where, w_j is weight of$j^{\,th}$criterion.

Step 4: Estimate the total relative importance based on Weighted Product Model (WPM).

$$Q_i^{(2)} = \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} \quad (7)$$

Step 5: In order to have more accurate ranking and to make the decision process smooth, a more generalized equation for calculating the total relative importance is formulated.

$$Q_i = \lambda Q_i^{(1)} + (\lambda - 1) Q_i^{(2)}; \quad \lambda = 0, 0.1, 0.2, \ldots\ldots, 1 \quad (8)$$

In WASPAS method, the best alternative will have the highest Q value. In this study, the value of λ was considered as 0.5. In Eq. (8), when the value of $\lambda$is 0, WASPAS method is altered to WPM, and when $\lambda$is 1, it becomes WSM method.

3. Results and Discussion

Analysis of the feasibility of SHS comparing with other renewable energy technologies in the Kalur Para village based on risk indicators is a complex, time-consuming and sensitive decision problem. However, in this study, an effort was given to solve the decision problem by considering nine (9) risk indicators to evaluate the feasibility of SHS with three (3) types of renewable energy technologies.

3.1. Output of BWM

The set of linear equations from table 3 were solved using the software package 'Solver Linear BWM'[15] and then relative weights were estimated. From table 4, it is seen that 'Force majeure risk (FMR)' obtained the highest weight of 0.289. The reason behind it might be the location of the study area, which is a high-risk zone for natural disaster, particularly flooding and sometimes storms throughout the monsoon season. Historically, flooding and river erosion is severe in the Fulchari upazila where the char land is 90% of the total upazila [16] . The 'Public resistance (PR)' obtained the lowest weight of 0.029 which shows least important risk factor. Most of the people living in the study area are simple, honest and humble. Although very few interest groups are there, but the number is insignificant. Moreover, people have strong social bonding and understanding among each other. Therefore, the possibility of creating problems by third parties is negligible and thus the risk of public resistance is almost zero. The weights of 'Theft and vandalism' and 'Load uncertainty' are same with a value of 0.062139. It reflects the equal importance of these two indicators. It is evident that the security of the study area is well monitored by local law enforcement authority and thus the plants will be protected from theft and vandalism. Similarly, Environmental Impact and Stakeholder Management weighted as 0.124279 which also indicates the equal importance. Generally, renewable energy technologies have low environmental impact. However, these technologies emit greenhouse gas even in lesser amount. The weight of Political instability was determined as 0.186418 which highlights the importance of this indicator. Bangladesh is a democratic country and the country is maintaining its political stability for the last 10 years. However, a remote village like Kalur Para could be instable due to local political conflicts.

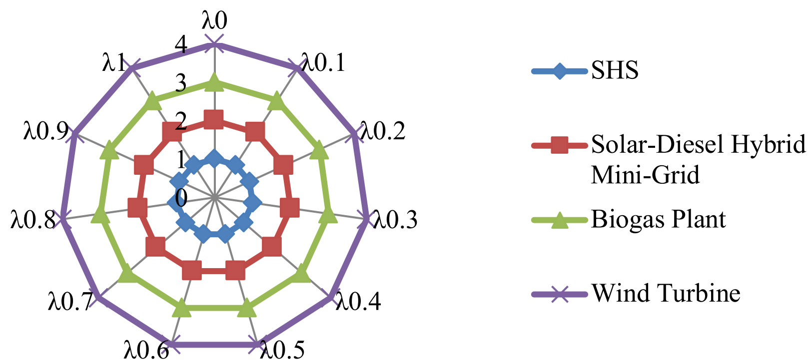

Figure 3. Sensitivity Analysis

Relief supply sometimes became a serious concern during flood and often due to relief distribution, local political and interest groups have conflicts. Thus, political instability could create delay during the renewable energy project implementation phase and can harm the existing renewable energy technologies. The risk indicator 'Inadequate business models' scored as 0.046605. The renewable energy technologies considered in the study area are not grid connected. Grid connected system require robust business model then off-grid system. Therefore, less concentration was given to that indicator.

Table 4. Weights obtained from BWM

Risk Indicators	**Weights**
Force majeure risk (FMR)	0.289984
Theft and vandalism (TV)	0.062139
Load uncertainty (LU)	0.062139
Geographical isolation (GI)	0.074567
Political instability (PI)	0.186418
Inadequate business models (IBM)	0.046605
Environmental impact (EI)	0.124279
Public resistance (PR)	0.02959
Stakeholder Management (SM)	0.124279

3.2. Output of WASPAS

The final step of the decision framework was to implement the WASPAS model to rank the renewable energy technologies. At first, using equation (3), the following decision matrix (9) was formed.

$$X_{ij} = \begin{bmatrix} 3 & 1 & 2 & 4 & 1 & 3 & 1 & 1 & 2 \\ 2 & 3 & 4 & 4 & 4 & 3 & 4 & 3 & 2 \\ 3 & 2 & 3 & 4 & 3 & 2 & 4 & 5 & 2 \\ 5 & 4 & 4 & 4 & 3 & 3 & 3 & 2 & 3 \end{bmatrix} \quad (9)$$

Then, using equation (4) and (5), the decision matrix (10) was normalised as below.

Finally, using equation (6), (7) and (8), the weights of the renewable energy technologies were estimated, which is shown in table 5. Results show that the Solar Home System (SHS) ranked 1, Solar Mini-Grid ranked 2, Biogas Plant ranked 3 and Wind Turbine ranked 4.

The result justified that SHS is the best option for Kalur Para. Bangladesh is the country with highest penetration of SHS, and still has additional potential market for it. It is a great achievement and example for other developing countries. Previously, it was stated that most of the people in the study area use SHS. However, it was unclear whether this type of technology is risk free and feasible. The results of this study revealed that SHS is the most risk-free technology. Shahsavari et al. [17] revelled that SHS is cost-effective and can fulfil household's energy demand, particularly in off-grid areas. This type of technology also easy to maintain and don't require the

$$\bar{x}_{ij} = \begin{bmatrix} 0.666 & 1 & 1 & 1 & 1 & 0.666 & 1 & 1 & 0.666 \\ 1 & 0.333 & 0.500 & 1 & 0.250 & 0.666 & 0.250 & 0.333 & 0.666 \\ 0.666 & 0.500 & 0.666 & 1 & 0.333 & 1 & 0.250 & 0.200 & 0.666 \\ 0.400 & 0.250 & 0.500 & 1 & 0.333 & 0.666 & 0.333 & 0.500 & 1 \end{bmatrix} \quad (10)$$

system components to be changed frequently. Moreover, SHS is highly environmentally friendly. Except "Force Majeure Risk", this technology has least risk than other renewable energy technologies. Solar-Diesel Hybrid Mini-Grid could be the 2nd alternative option in the study area. The function of diesel generator is to provide backup power when there is an insufficiency of electricity generation from solar energy. Although Solar-Diesel Hybrid Mini-Grid supplies bigger amount of power than SHS, but practically people there don't have the generated power demand. It is because 95% people can't afford high electricity consuming appliances like computer, TV, freezer, ceiling fan etc. in their homes. Most people use electric bulb as the only electric appliance, where SHS is capable enough to power it. A recent study showed that per unit cost of energy of SHS for a household with 4 CFL (compact fluorescence lamps), 3 alternating current (AC) fans and 1 television (TV) is around USD 0.211/KWh [18]. Therefore, technically it could be said that if the people of Kalur Para village use only 2-3 CFL bulbs, the cost of energy will be reduced significantly. The tariff of the first solar-diesel mini grid in Bangladesh is USD 0.40/KWh [19]. Therefore, it could be also said that SHS is economically more viable than the solar-diesel hybrid mini grid. Moreover, use of diesel generator has worse effect on the environment due to higher GHG emissions. Regarding the biogas plant it is essential to have raw material, particularly cow dung. Unfortunately, due to the backward location and flood-prone area, the village is suffering from extreme poverty and thus the purchase capacity of the local people is meagre. Therefore, it is not feasible for them to buy domestic animals, with only 6-7% owning cows. There is high risk of flood and bad smell from the plant, which could be problematic. Technologies like wind turbines create noise and its blades kill birds. It is estimated that in USA annually 234,000 birds are killed by collision with wind turbines [20]. In Bangladesh, coastal areas are more feasible for wind energy due to high wind speed. However, the study area is in the northern part of the country and thus, do not have significant potential for wind energy. A study conducted by World Bank showed that the study area is not feasible for wind farm due to steepness of the land and flooding [21]. Due to heavy flood, soil could soften and thus, the foundation of the wind tower could collapse. Therefore, there is no wonder that wind turbine is ranked in last position.

Sensitivity analysis was performed by changing the values of λ from 0 to 1 which is shown in Figure 3. The result showed that even changing the values ofλ, the ranking order of the renewable energy technologies was not changed. It indicated that the proposed decision framework is robust, valid and vigorous.

Table 5. Ranking of renewable energy technologies

Types of Renewable Energy Technologies	$Q_i^{(1)}$	$Q_i^{(2)}$	Q_i ($\lambda = 0.5$)	**Rank**
SHS	0.846	0.829	0.837	1
Solar-Diesel Hybrid Mini-Grid	0.617	0.525	0.571	2
Biogas Plant	0.568	0.516	0.542	3
Wind Turbine	0.510	0.460	0.485	4

4. Conclusion

The study showed that SHS is the most feasible and risk-free option compared with other renewable energy technologies in Kalur Para village. However, this system has some certain challenges as well. Owing to the remoteness of the concerned location, the transportation system in the village is very poor. Therefore, it is often difficult to transport the system components of the SHS in the village. Most of the people in the village are unwilling to pay for a SHS at their own costs. Rafique [22] showed that the electricity rate from off-grid PV system is found to be 50 to 55% cheaper compared to conventional electricity supply. Okedu and Al-Hashmi [23] found that the payback period of solar PV systems, for electrifying a small off-grid community, is approximately 4 years. Therefore, some financial scheme could be introduced to encourage the local people in Bangladesh to buy SHS. Kabir et al. [24] proposed some financial schemes, such as subsidy on SHS purchase and maintenance, rational interest rates, and acceptable loan period. The author also showed that SHS can be economically beneficial to 71% of the householders in Ghatail upazila, located in the Tangail district of Bangladesh. It is also evident that political commitment and stakeholder management regarding SHS in the study area is strong. The Infrastructure Development Company Limited (IDCOL) plays the key role to provide loans for purchasing SHS. The organization gives the fund to the local NGOs, who give loans to customers for purchases. One study indicated that government subsidies significantly induced the installation of rooftop PV, although it influences price increase [25]. IDCOL also have disaster management fund which acts as insurance for customers affected by cyclones [26]. Additionally, the awareness and training program regarding the operation and maintenance (O&M) of SHS could be initiated.

Micro-grid, with central solar plant, could also be explored as a renewable energy technology, which may solve the issue of maintenance of individual SHSs; but it may also affect the cost of energy. In future, if the electric load increases due to the excessive use of high-powered electrical appliances and establishment of small industry, Solar-Diesel hybrid system could be initiated as an alternative option in the study area. However, before initiating this system a technical and economic feasibility study need to be done, special concentration should be given on risk factor. The proposed decision model can be used to analyse the feasibility of different types of renewable energy technologies based on risk factors in any country, particularly developing ones. Furthermore, the proposed framework can be used by different researchers, consultants, and policymakers.

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