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Modeling the Potential and Challenges of Solar Energy Use in Rural Bangladesh: A Scenario Analysis

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Abstract: The main objective of this study is to know the current status of solar energy use in rural areas and how we can create an empirical model for the rural people of Bangladesh to use the potential of solar energy. A mixed methods approach such as a semi open-ended questionnaire survey and environmental systems analysis tools (e.g. scenario analysis, DPSIR Frame work) have been applied in this current study. In this study, a Community Response to Solar Energy Approach (CReSEA) model has been developed with the views of a total of 450 households on the challenges of using solar energy in remote rural areas of Bangladesh. From the data analysis, it is realised that the solar home system is widely used in Gabura Union, Shyamnagar Upazila of Satkhira, but the application of solar home system is relatively less in Mohanpur of Ullapara Upazila of Sirajganj district. But in Satpoa Union of Sarishabari Upazila of Jamalpur District compared to Ullapar Upazila of Sirajganj, the situation of solar energy application and utilization is much better. One other hand, it is observed that a large number of farmers are used solar pump almost 35.12% of total irrigated area in Gabura Union at the Shyamnagar Upazila in Satkhira district. Similarly, according to the surveyed reasults that 30.12 % total irrigation areas are used solar pump at the Satpoa Union at the Sarishabari Upazila in Jamalpur district and the lowest numbers of farmers have been irrigated the 10.47% of total irrigated areas at Mohanpur Union at Ullapara Upazila in Sirajgonj district. The results of the study also examined that the significant benefit of solar power in rural areas is increased availability of solar energy. The case study, the Mohanpur Union at Ullapara Upazila in Sirajgonj districts has a big gaps to utilize the solar energy use because of the local people are not aware enough regarding the feasibility of solar home system. The developed Community Response to Solar Energy Approach (CReSEA) model would be able to build the awareness to the rural people regarding the use of solar energy on behalf of rural electricity and keroshin (diesel) oil in rural areas in Bangladesh. Although, the lack of budget and time, this Community Response to Solar Energy Approach (CReSEA) model has been theoretically validated, but its practical side has not been tested through the pilot project. The practicality and accuracy of this model can be verified in further research.

Keywords: Solar Energy, Rural Poverty, Solar Home Systems, CReSEA model, Bangladesh

1. Introduction

The overall current energy situation of Bangladesh is thoughtful, and natural gas is used in the country's major power plants to produce the electricity and industrial goods (Kumar et al., 2010; Khan, 2012; Raouf et al., 2016; Gillani et al., 2021). According to recent data, the economic sectors in Bangladesh are growing quickly and poverty rates

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are reducing rapidly (Hossain et al., 2011; Khan et al., 2012; Hossain et al., 2016). Considering the energy demand of the country the solar home systems are more cost-effective for micro-enterprises and homes with low-income generation activities than for households who solely use it for lighting (Islam and Mondal, 2009; Hasan et al., 2012; Sarker et al., 2020). Bangladesh is a store house of solar energy due to global position in the sub-tropical region. The solar power is the energy which is obtained by the capturing heat and light from the sun (Singh, 2013; Sharif et al., 2018). In a simple definition, energy from the sun is referred to as solar energy (Chu and Meisen, 2011; Ahmed et al., 2019).

Bangladesh, a developing country has a huge energy demand because of its growing population and the upcoming energy demand and consumption (Manju and Sagar, 2017; Khan et al., 2020). The country is largely dependent on non-renewable energy sources like burning of fossil fuels, petroleum and natural gas etc. (Baky et al., 2017; Amin et al., 2022). But as much as the country is dependent on non-renewable sources, it has a huge scope with solar energy would be the cost-effective for current and future generation (Halder et al., 2013; Chowdhury et al., 2014; Khan et al., 2019).

Bangladesh is a south Asian country that lies between 20°34' and 26°39' north latitude and 80°00' and 90°41' east longitude. That's why it t is an excellent place for utilizing solar energy. Furthermore, because it is a subtropical country, sunshine is abundant for 70% of the year Batteiger, 2015; Masud et al., 2020). Considering the many suitable condition and favourable reasons the solar panels are quite effective in Bangladesh (Chowdhury et al., 2014; Nandal et al., 2019; Bhuiyan et al., 2021). On the other hand, some challenges that the solar sector faces are in the form of: high implementing costs, local politics, the seasonality, the cloudiness and the lack of consumer awareness in rural areas (Halder et al., 2015; Sarker et al., 2020). Globally, the solar energy is considered as a green energy because it does not emit greenhouse gases while fossil fuel and other energy sources emit huge greenhouse gases that make the earth warm (Podder et al., 2015; Khan and Martin, 2015; Khandker et al., 2018; Karim et al., 2019). Solar energy is plentifully available and has been utilized since long both as electricity and as a source of heat (Kumar et al., 2010; Singh, 2013). The other form of obtaining solar energy is through thermal technologies, which give two forms of energy tapping methods (Komatsu et al., 2011; Sumathi et al., 2017); Such as: 1) the first is solar concept, which focuses solar energy to initiative thermal turbines; and 2) the second method is heating and cooling systems used in solar water heating and air conditioning respectively (Rashid et al., 2012; Rouf et al., 2016; Sarker et al., 2020; Li et al., 2019).

Many people in rural areas in Bangladesh have to pay a lot of money for electricity. But considering other sources of energy the solar energy price and installation cost are quite low (Bhusan et al., 2015: Biswas and Iqbal, 2018). And as the demand for non-renewable energy grows, its value will skyrocket in the future, and solar energy can be used at a much lower cost (Khan and Martin, 2015; Khandker et al., 2018). Though some NGOs and Government has tried to make guidelines for implementing the solar energy systems in the rural areas in Bangladesh widely but it is not satisfactory initiatives at all (Gulagi et al., 2020). According to Islam et al., 2015 and Rahman et al., 2020, the renewable energy such as solar and clean wind power systems in Bangladesh will be able to meet 70 percent of energy needs. Particularly, the solar photovoltaic (PV) systems are becoming more popular in rural regions for powering homes and small enterprises (Boamah, 2020).

Bangladesh is a disaster prone country in the world. Especially, during monsoon periods, most of time a devastating floods have been occurred as two thirds of the territory is only 5 metres above sea level (Demirbas, 2009; Khan, 2013; Halder et al., 2015; Mazumder and Islam, 2018; Islam et al., 2021). Energy sectors of Bangladesh are mostly dependent on fossil fuels, natural gas and oil for generating the electricity and to fulfil the demand of energy (Mazumder and Islam, 2018). According to the scientific evidences and case studies, it is found that the solar home system (SHS) provides a variety of socioeconomic benefits, such as improved quality of life, increased income and employment, and improved education for rural families (Khan, 2012; Islam et al., 2014; Hasan et al., 2016).

Though it is unfortunate that the most of the least developed and developing countries the major power grids provide the energy into the urban and semi-urban areas due to the national energy regulations and energy policy (Marzia et al., 2018). However, policymakers and the local government will not interested to supply the energy in the rural areas which is characteristic of a number of rural regions in developing countries like Bangladesh (Khan and Martin, 2015; Khandker et al., 2018). That's why most of the villages and remote rural areas are powerless to supply the numerous of villages that are all distant from one another and do not have the resources that can be able to make it profitable (Lyle and McCallam, 2008; Urmee and Harries, 2011). Still now most of remote rural areas of Bangladesh are facing the proper energy deficiency. Creating awareness among the rural residents and developing a well-defined guideline to overcome the socio-economic and financial challenges is the major gap in the current research. For considering this situation, through this study, it has been developed a community response based solar energy approach model for using the appropriate sustainable solar home system in rural areas.

1.1 Significance of the Study

Due to huge population and rising the demand of energy consumption in Bangladesh, the need for energy is increasing day by day (Halder et al., 2015). The energy shortage of the country is currently very alarming. Filling up the energy demand of this highly populated country has become difficult for the energy sector of Bangladesh. In this aspects, implementing the solar energy is an appropriate application for providing the opportunity to ensure the cheap power at the remote rural areas in Bangladesh (Rahman and Ahmad, 2013). Though current government have tried to improve the production of electricity in many ways but still this solar energy sector is not well established in the country (Marzia et al., 2018). The energy regulations and the Government of Bangladesh set a target for generating 5% of its electricity from renewable energy sources by 2015 as well as 10% by 2020 but unfortunately due to lack of increase the productivity of solar energy it was not achieved well. In this study, though the solar home system is the most appropriate options and solution to reduce the energy deficiency in the rural Bangladesh but the high investment costs and a lack of technical knowledge are the major obstacle to SHS adoption and implementation (Ahammed and Taufiq, 2008; Hossain, 2018). Considering the energy crisis of Bangladesh, the current research work has been completed with the aim of implementing our potential solar energy sector in rural areas. In this study it was tried to assess the actual scenarios of solar energy application in household levels and irrigation contexts. Union level data has been collected and analysed in three Upazilla's with different socioeconomic and environmental conditions in Bangladesh. A model has

been created through the potential and challenges of solar energy use by analysing three case study of solar energy implementation scenarios by applying different scientific methods. Considering all above all the situation and issues the current research themes, methods and results are very significant for the case country Bangladesh.

1.2 Aim and Objective of the Study

The aim of this study is to assess the differentiation of solar energy adoption at the households and irrigation section in rural areas of Bangladesh. This study also tried to identify the major challenges for implementing the solar home system (SHS) at the rural areas in Bangladesh. Also, a conceptual model has been developed in this study which would be pathways to understand the potentials of solar energy in rural Bangladesh which can then bring economic development and also improve the quality of life for people living in the country.

Specific objectives:

i) To assess the differentiation of solar energy adoption at the households and irrigation section in rural areas of Bangladesh;

ii) To develop a policy model to minimize the challenges of solar system installation at the rural areas in Bangladesh

2. Study Area, Data Sources and Methodology

In this study, the both primary and secondary data have been collected from many sources. For collecting the secondary sources web based bibliographic analyses have been applied for screening the secondary data (Jandee et al., 2015). The keywords are used as solar energy, rural electrification, solar home system, status, socio economic challenges, solution, financing and support of micro finance etc. (Palit, 2013; Khan et al., 2020). In this study, three unions of three Upazilla in three regions of Bangladesh have been considered as case study areas (Table-1).

Table-1: Sampling households for questionnaire survey from three study areas in different districts in Bangladesh

District Name	Upazilla	Union	Total number of Households	Sampling Households	Methods
Satkhira	Shyamnagar	Gabura	7491	150	Questionnaire Survey
Sirajgonj	Ullapara	Mohanpur.	8931	150	Questionnaire Survey
Jamalpur	Sarishabari	Satpoa	7229	150	Questionnaire Survey
Total Sampling Households for surveying the solar home system				**450**	

Source: Questionnaire Survey, 2021

A separate questionnaires were used to collect field survey from solar home system designer, resellers, and consumers separately (Sun et al., 2015; Halder, 2016). These structured questionnaires have been developed considering the respondents educational and socioeconomic status of the remote rural areas in Bangladesh (Laufer and Schäfer, 2011). And before conducting the field survey, the questionnaires have been brought into performance test through pre-test surveys. Necessary adjustments and modification were executed to have been done prior to conduct the primary survey in the three case study areas.

2. Developed Community Response of Solar Energy Approach (CReSEA) Model

2.1 Application of DPSIR Framework

The Driver-Pressure-State-Influence-Response (DPSIR) model provides a framework is used in this study (Lewison et al., 2016). The DPSIR model is a development of the OECD's pressure-state-response paradigm (Mandić, 2020). Data and information on all of the numerous parts in the DPSIR chain are collected as a first step (Frederiksen and Kristensen, 2008). Theoretical links between these various characteristics are then proposed in this study through DPSIR model. Most of the driving forces are the rural socio-economic aspects and human activities, which increase or mitigate pressures on the situation of energy sectors at rural areas in Bangladesh.

2.2 Implementation of SWOT Analysis

SWOT (strengths, weaknesses, opportunities, and threats) analysis is a strategy for identifying and evaluating internal and external strengths and weaknesses, as well as opportunities and threats that influence current and future operations of solar energy prospects and challenges at the rural areas in Bangladesh (Ommani, 2011; Bull et al., 2016). A SWOT analysis is a valuable tool for strategic planning which is widely used in this current research (Abubakar and Bello, 2013; Stewart and Shamdasani, 2014). It is important to point out that in this study some the strengths of rural inhabitants to the perceptions of solar home installation and weaknesses are current or backward-looking as example SHS installation cost and opportunities and threats are forward-looking.

2.3 Scenario Analysis

Scenario analysis techniques are all terms used to describe a strategic planning process used by certain businesses to develop adaptable long-term strategies (Tourki et al., 2013; Batrouni et al., 2018). It is mostly an adaptation and generalization of traditional military intelligence procedures. In this study, the scenario analysis has been applied to explore the growth and expand scenarios of solar energy in Bangladesh.

3. Results and Discussions

3.1 Solar Energy: Scenario Analysis (1973-2050) in Bangladesh

According to the scientific evidences, over 60% of total households are located in rural areas, which are still not covered with power grids or electricity facilities (Amin et al., 2022). The scenarios of IDCOL, approximately 62% of the population is now well linked to the national electricity grid (Anam et al., 2022). One of the main benefits of the solar energy application and solar home system (SHS) installation in the house is the lower

utility bills of electricity (Wang et al., 2018). The solar panels can offset the electricity usage at home and reduce how much the people end up paying for utilities over time. As mentioned before the poverty levels in Bangladesh have just started to fall (Komatsu et al., 2011; Saim and Khan, 2021). However, this situation will remain uneven for sometimes until both the rural and urban if the energy policy will not be revised. The Table 2 shows the exploratory/descriptive scenarios of solar energy implementation in Bangladesh from 1973 to 2020 and the future scenarios are defined in this table from 2020 to 2050, though most of the uncertainties will be occurred. We found that the solar energy using and SHS installations are increased by the activities of IDCOL, many NGOs and several private companies jointly.

Table 2: Exploratory/descriptive scenarios of solar energy implementation in Bangladesh from 1980 to 2020 and the future scenarios are defined in this table from 2020 to 2040

Scenarios	Time Phase	Exploratory Scenarios	Sources
S_0	1973	Baseline scenario (assuming no intervention is made)	
S_0-S_1	1973-1983	There is a very little ideas promoted to generate the solar energy in Bangladesh.	Shahan (2014)
S_1-S_2	1983-1993	The distribution of solar home systems (SHSs) is being promoted mainly by the IDCOL that is the private sector companies and NGOs based on the direct-sale approach. It is also the provision of refinancing funds for micro-financing of SHSs to participating organizations.	Asaduzzaman et al. (2013)
S_2-S_3	1993-2003	In the periods of 1993-2003, the solar energy concept is denoting by the government agency namely Infrastructure Development Company Limited (IDCOL), which began the solar home system project in 2003.	Rahman (2015); IDCOL (2016)
S_3-S_4	2003-2013	In the periods of 2003-2013, using solar energy for rural and off-grid electrification through solar photovoltaic and home systems has been started locally. In this with 3.5 million households about 10 percent of the country's total had installed SHS by the end of 2013.	Mridul et al., (2021); IDCOL (2018)
S_4-S_5	2013-2023	In the periods of 2013 due to inadequate generation capacity expansion was very slow. But from the beginning of 2014 the total installations capacity of SHS has reached 150MW in the year 2013–2020 with 185.185% increase over the previous year.	BIDS (2012); IDCOL (2020)
S_5-S_6	2023-2033	According to IPPC direction by the reduced kerosene (diesel) combustion due to the reduction in CO_2 and black carbon emissions the country policymakers will be bound to generate the renewable energy like solar energy.	IDCOL (2020) Islam et al. (2021)

Scenarios	Time Phase	Exploratory Scenarios	Sources
S_6-S_7	2033-2043	In this periods 2033-2043, the SHS are estimated at 9.6 million tone CO_2. The situation of Bangladesh will be effectively improved.	Islam et al. (2021)
S8	2050 to End point	Lots of uncertainty to predict this point because after 2043 the social and economy condition Bangladesh would be going up as like as developed country so that Bangladesh needs to improve the power sector with nuclear energy sector as well.	Anam et al (2022)

Source: Policy evaluation through the scientific contents analysis and scenario analysis by the Author, 2022

3.2 Household based solar energy applications and utilizations scopes

Due to the position of north hemisphere, Bangladesh has the opportunity to capture the solar energy extensively (Azimoh et al., 2015). By supporting with the World Bank and other NGOs organizations, along with the private sector the government Bangladesh are working to generate affordable, solar-energy electricity to places where the electricity grid doesn't extent (Halder et al., 2015).

Table 3: Household based solar energy applications and utilizations of actual adoption and predicted adoption in three case study areas

Household based solar energy applications and utilizations current status	Shyamnagar Upazila (150 households)		Ullapara Upazila (150 households)		Sarishabari Upazila (150 households)	
	Actual Adoption	Predicted Adoption	Actual Adoption	Predicted Adoption	Actual Adoption	Predicted Adoption
Solar Home System (SHS)	28	49	6	25	21	44
Irrigation by Solar Energy	21	32	9	21	12	35
Solar PV	10	10	10	16	25	14
Rooftop solar	7	7	2	3	9	9
Rural Electrification	27	23	70	40	42	16
Keroshin Oil	26	10	41	29	27	12
Biomass based electricity	7	7	7	9	7	9
Wind energy	10	3	1	2	2	4
Hydropower	9	4	1	2	2	4
Others	5	5	3	3	3	3
Total households surveyed	150	150	150	150	150	150

Source: Questionnaire survey and model prediction by author, 2021

Continuous blooming of Bangladesh's economy an average growth rate of 8%, and demand for electricity is rising fast so that it would be better if the policymakers give the emphasis to produce the solar energy as much as possible (Hossain and Rahman, 2021). In the case study area, it is observed that the solar home systems in Gabura Union, Shyamanagar Upzilla, Satkhira District are widely used but in case of Mohanpur Union, Ullapara Upazila, Sirajgonj district, the solar home system are used very insignificant. But comparatively, Mohanpur Union it is observed that the solar energy application and utilization status are much better in at Satpoa Union, Sarishabari Upazila in Jamalpur district (see in Table 3).

If the country can support to develop the solar irrigation systems it would be green technology option for irrigation, allowing the use solar energy for water pumping, replacing fossil fuels as energy source, and reducing greenhouse gas (GHG) which are emitted from agricultural sectors (Talukder and Shamsuddin, 2012; Kartal et al., 2020). The energy regulations authority in country if they able to convert the diesel or electricity-powered irrigation pumps into solar pumps surely Bangladesh will be able to reduce the greenhouse gases each year. Therefore, solar pump may be used for irrigation in crop production for sustainable green agriculture (Hossain et al., 2015). In the Table 4, it is observed that irrigation facilities have been used by the framers different ways of energy options of irrigation systems. It is a good sign that a large number of farmers are used solar pump almost 35.12% of total irrigated area in Gabura Union at the Shyamnagar Upazila in Satkhira district. Similarly, the respondents highlighted that 30.12 % total irrigation areas are used solar pump at the Satpoa Union at the Sarishabari Upazila in Jamalpur district and the lowest numbers of farmers have been irrigated the 10.47% of total irrigated areas at Mohanpur Union at Ullapara Upazila in Sirajgonj district.

Table 4: Irrigation facilities used by several mode of irrigation systems

Irrigation Facilities in the Three Case Study Area			
	Shyamnagar Thana	**Ullapara Thana**	**Sarishabari Thana**
	% of Total Irrigated Area	% of Total Irrigated Area	% of Total Irrigated Area
Deep Tube wells	18.21	33.23	21.23
Shallow tube wells	20.12	21.12	20.54
Low lift pumps	4.78	8.78	4.78
Low lift pumps	4.56	6.56	4.56
Manual & Artesian well	3.12	3.12	3.12
Gravity flow	0.92	1.92	0.92
Traditional method	3.51	7.43	4.56
Solar pump	35.12	10.47	30.12
Dug well	8.43	7.37	7.72
Others	1.23	3.52	2.45
Total	100	100	100

Source: Questionnaire Survey 2021

According to the Fig. 1: Surveyed and model predicted households wise solar energy used in Shyamanagar Upazila it is observed that solar home system and irrigation by solar energy are used in Gabura Union widely. On the other hand, using of solar photovoltaic (PV) and rooftop solar are low in the context of rural electrification and keroshin (diesel) oil. It is also revealed that a large number of household are used the rural electrification service and keroshin (diesel) oil. But if the rural people are interested to use the solar energy in their home and the SHS company provided the feasible SHS package with low installation cost the predicted adoption of solar energy applications will be increased intensely and using of rural electrification and keroshin oil will be decreased remarkably.

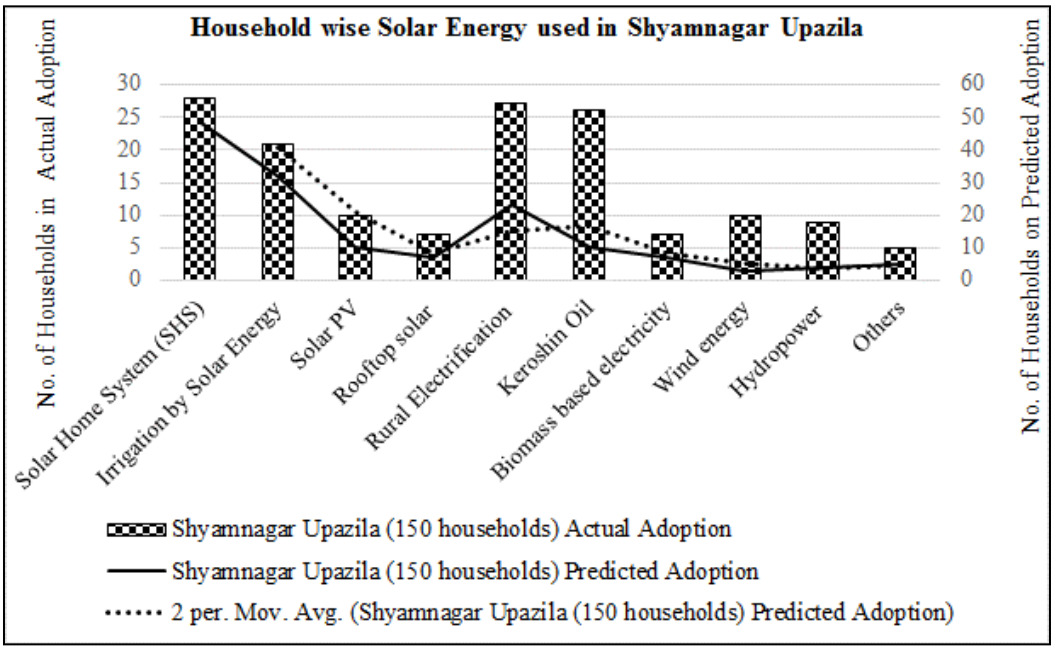

Fig. 1: Surveyed and model predicted households wise solar energy used in Shyamanagar Upazila.

According to the **Fig. 2:** Surveyed and model predicted households wise solar energy used in Sarishabari Upazila it is observed that solar home system and irrigation by solar energy are used in Mohanpur Union widely.

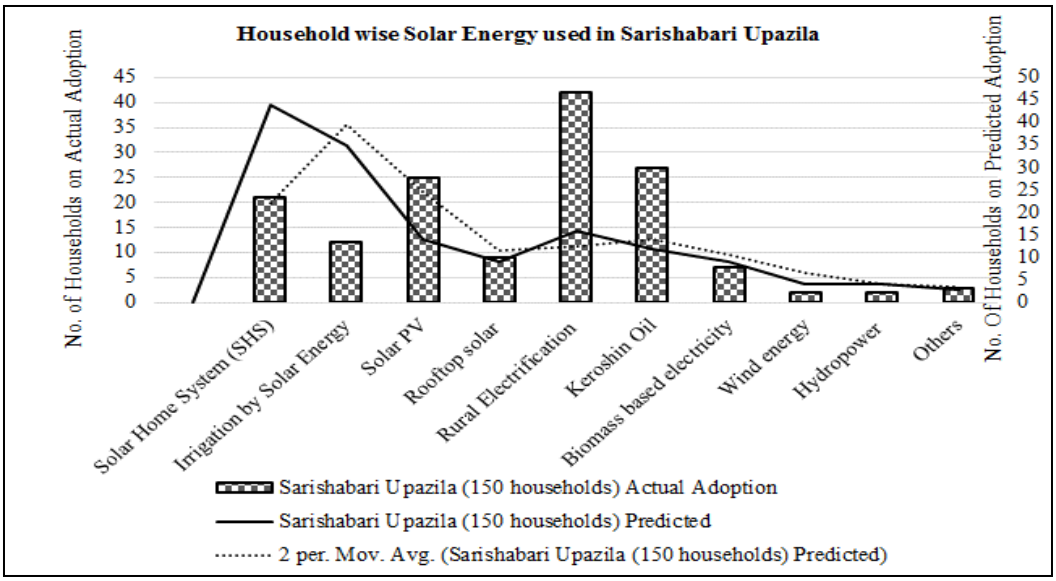

Fig. 2: Surveyed and model predicted households wise solar energy used in Sarishabari Upazila.

On the other hand, using of solar photovoltaic (PV) and rooftop solar system at Mohanpur Union in Sarishabari upazila are low in the context of rural electrification and keroshin (diesel) oil. It is also revealed that a large number of household are used the rural electrification and keroshin (diesel) oil. But if the rural people are interested to use the solar energy in their home and the SHS company provided the feasible SHS package with low installation cost the predicted adoption of solar energy applications will be increased dramatically and using of rural electrification and keroshin (diesel) oil will be decreased remarkably.

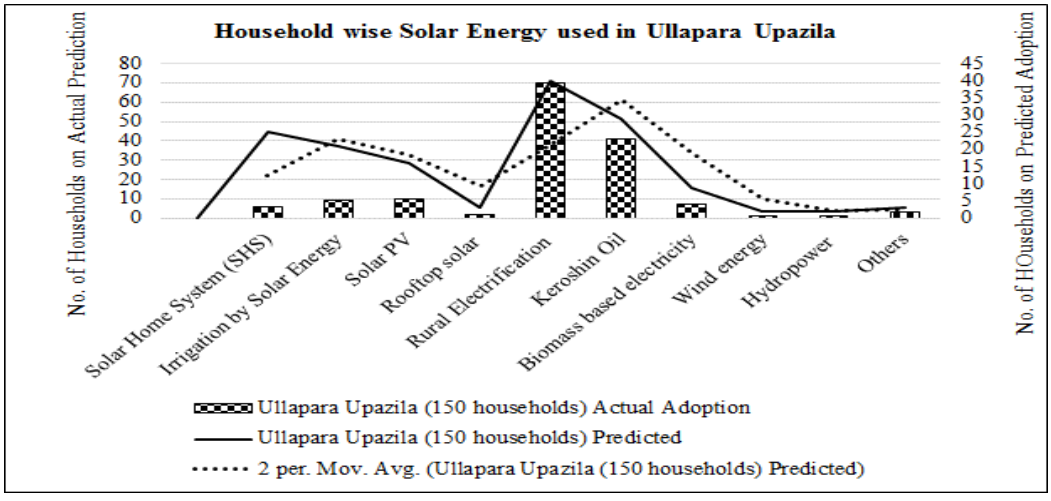

Fig. 3: Surveyed and model predicted households wise solar energy used in Ullapara Upazila.

The results of the study revealed that the significant benefit of solar power in rural areas is increased availability. The case study rural areas in Mohanpur Union at Ullapara Upazila in Sirajgonj districts lack this resource because the local pole are not aware enough regarding the feasibility of solar home system. The Fig. 3**:** shows the surveyed and model predicted households wise solar energy used at the Mohanpur Union in Ullapara Upazila, Sirajgonj district are very low while the use of rural electrification and keroshin oil are quite high.

3.2 Solar Energy Implementation through CReSEA Model

Though the government of Bangladesh has tried to develop the Solar Home System (SHS) but still the electricity sectors are not improved to be a positive alternative in providing affordable electricity (Zubi et al., 2019). Being a tropical region, Bangladesh has the suitable condition supply of solar energy. So, there are lots of possible benefits and positive impacts by properly using this solar energy sources (Khan, 2012; Khan et al., 2014). The Table-5 shows the selective Parameters Process and Functions: Rural Community Approaches of solar energy development remote rural areas in Bangladesh. However, to analyse the future prospects and challenges there is a need to evaluate the present scenarios of SHS and to build a model for improving the solar energy sectors in Bangladesh. According to the current impact of SHS, an efficient model to understand the upcoming energy crisis. That's why, in this study, it was tried to develop a Community Response of Solar Energy Approach (CReSEA) model for solar home systems (SHS) and to build the awareness to the rural people regarding the use of solar energy on behalf of rural electricity and keroshin (diesel) oil in rural areas in Bangladesh.

Table-5: Selective Parameters Process and Functions: Rural Community Approaches of solar energy development remote rural areas in Bangladesh

Code	Parameters Process and Functions: Rural Community Approach	References
LC	**Taking the local context into account with the actors in the field and to make the priority needs to install SHS in rural areas**	Lyle and McCallam (2008) Amin and Khan (2020)
LC_a	Monthly income of head of the households	Anam et a. (2022)
LC_b	Communication and transportation cost between district city	Sumathi et al. (2017)
LC_c	Family composition and school going children of the households	Podder et al. (2021)
LC_d	Locational and seasonal aspects of the SHS installation area	Mostafaeipour et al. (2021)
LC_e	Rank the priority needs for the households	Qays and Yasmin (2020)
CoI	**Build the rural ownership and involvement for SHS implementation and learning how to function the solar home facilities**	Lyle and McCallam (2008) Amin and Khan (2020)
COI_a	Educational level of the households family members	Liza et al. (2020)
COI_b	Attitude of community ownership towards the SHS plants	Nandal et al. (2019)
COI_c	Willingness to learn how to operate the SHS	Kirchhoff and Strunz (2019)

Code	Parameters Process and Functions: Rural Community Approach	References
COI_d	Households head attitude towards the payment of Installation cost	Khan (2019a)
COI_e	Are available facilities through appropriate support?	Palit (2013)
TLO	**Training the local operators, users and to utilize for the maintenance of the equipment**	Lyle and McCallam (2008) Anam et a. (2022)
TLO_a	Does the facilities available to train the operator?	Mridul et al. (2021)
TLO_b	Does the facilities available to train the user households?	Anam et a. (2022)
TLO_c	Are the maintenance of the equipment?	Zhao et al. (2019)
TLO_d	Willingness to take the training by the operator	Kabir et al. (2016)
TLO_e	Willingness to take the training by the household level users	
LCM	**Model the legitimate and competent management committee to ensure that the solar home facilities in the study area**	Lyle and McCallam (2008) Anam et a. (2022)
LCM_a	National energy regulation and policy and solar energy implementation	Marzia et al. (2018)
LCM_b	Linking the solar energy facilities among other renewable energy	Ishraque et al. (2020)
LCM_c	Rural energy demand and country energy policy	Amin et al. (2022)
LCM_d	Rural legitimacy and role of competent management committee	Harun (2015)
LCM_e	Bridge with country policymakers and NGOs/ SHS business partner	Huq (2019)

3.3 Equation and Scientific Approach of Proposed CReSEA Model

The major mathematical equation of the model processes and definitions are:

$$\int_{i=1}^{n} SHS = \{(\sum_{i=1}^{n} LC) + (\sum_{i=1}^{n} COI) + (\sum_{i=1}^{n} TLO) + (\sum_{i=1}^{n} LCM)\}\text{----------} \quad \text{(i)}$$

Where,

$$(\sum_{i=1}^{n} LC) = \{\int_{i=1}^{n} LC_a + LC_b + LC_c + LC_d + LC_e\}\text{----------} \quad \text{(ii)}$$

$$(\sum_{i=1}^{n} CoI) = \{\int_{i=1}^{n} CoI_a + CoI_b + CoI_c + CoI_d + CoI_e\}\text{----------} \quad \text{(iii)}$$

$$(\sum_{i=1}^{n} TLO) = \{\int_{i=1}^{n} TLO_a + TLO_b + TLO_c + TLO_d + TLO_e\}\text{----------} \quad \text{(iv)}$$

$$(\sum_{i=1}^{n} LCM) = \{\int_{i=1}^{n} LCM_a + LCM_b + LCM_c + LCM_d + LCM_e\}\text{----------} \quad \text{(v)}$$

Table-6: Matrix of the Community Response of Solar Energy Approach (CReSEA) Model

Dominated Parameters		**LC**	**CoI**	**TLO**	**LCM**
Minor Parameters					
LCa	MPd	LC× LCa	CoI×LCa	TLO×LCa	LCM×LCa
LCb		LC× LCb	CoI×LCb	TLO×LCb	LCM×LCb
LCc		LC× LCc	CoI×LCc	TLO×LCc	LCM×LCc
LCd		LC× LCd	CoI×LCd	TLO×LCd	LCM×LCd
LCe		LC× LCe	CoI×LCe	TLO×LCe	LCM×LCe
CoIa	MPd	LC×COIa	CoI×CoIa	TLO×COIa	LCM×COIa
CoIb		LC×COIb	CoI×CoIb	TLO×COIb	LCM×COIb
CoIc		LC×COIc	CoI×CoIc	TLO×COIc	LCM×COIc
CoId		LC×COId	CoI×CoId	TLO×COId	LCM×COId
CoIe		LC×COIe	CoI×CoIe	TLO×COIe	LCM×COIe
TLOa	MPm	LC×TLOa	CoI×TLOa	TLO×TLOa	LCM×TLOa
TLOb		LC×TLOb	CoI×TLOb	TLO×TLOb	LCM×TLOb
TLOc		LC×TLOc	CoI×TLOc	TLO×TLOc	LCM×TLOc
TLOd		LC×TLOd	CoI×TLOd	TLO×TLOd	LCM×TLOd
TLOe		LC×TLOe	CoI×TLOe	TLO×TLOe	LCM×TLOe
LCMa	MPm	LC×LCMa	COI×LCMa	TLO×LCMa	LCM×LCMa
LCMb		LC×LCMb	COI×LCMb	TLO×LCMb	LCM×LCMb
LCMc		LC×LCMc	COI×LCMc	TLO×LCMc	LCM×LCMc
LCMe		LC×LCMd	COI×LCMd	TLO×LCMd	LCM×LCMd
LCMe		LC×LCMe	COI×LCMe	TLO×LCMe	LCM×LCMe

***MPd = Model Parameters (Dominated):** Taking the local context into account with the actors in the field and to make the priority needs to install SHS in rural areas.

***MPd = Model Parameters (Dominated):** Build the rural ownership and involvement for SHS implementation and learning how to function the solar home facilities

***MPm =Model Parameters (Minor Influencing):** Training the local operators, users and to utilize for the maintenance of the equipment

***MPm=Model Parameters (Minor Influencing):** Model the legitimate and competent management committee to ensure that the solar home facilities in the study area

According to the respondent's opinion, it was calculated the weighted value of each dominated parameters and minor influencing parameters as Table 6. The percentages of the respondents opinions have been consider the calculation of weighted of each parameters. Considering the opinions of the respondents of the questionnaire survey it is valued LC=4, CoI=3, TCL=2 and LCM=1. Similarly, if it is valued for the Minor Influencing Parameters (MIP) are LCa=0.5, LCb=0.4, LCc=0.3, LCd = 0.2 and LCe=0.1. Accordingly, CoIa=0.49, CoIb=0.39, CoIc=0.29, CoId=0.19 and CoIe=0.09. At the same

processes, it is considered a less influencing value TLOa=0.48, TLOb=0.38, TLOc=0.28, TLOd=0.18 and TLOe=0.08. According the respondents opinions, it is assumed that the very little influencing factors and actors are related as LCMa=0.47, LCMb=0.37, LCMc=0.27, LCMd=0.17 and LCMe=0.07. The Table-7 shows the matrix index for calculating the impact weight for rural legitimacy and energy policy for solar energy inhalation in remote rural areas in Bangladesh.

Table-7: Parameters for building the Community Response of Solar Energy Approach (CReSEA) Model for calculating the Impact Weight for rural legitimacy and energy policy for solar energy inhalation in remote rural areas in Bangladesh.

Code DP	**LC**	**CoI**	**TLO**	**LCM**	**Row Total Scores**	**Rank**
Code MIP						
LCa	4×0.50=2.00	3×0.50=1.50	2×0.50=1.00	1×0.50=0.50	5	1
LCb	4×0.40=1.60	3×0.40=1.20	2×0.40=0.80	1×0.40=0.40	4	5
LCc	4×0.30=1.20	3×0.30=0.90	2×0.30=0.60	1×0.30=0.30	3	9
LCd	4×0.20=0.80	3×0.30=0.60	2×0.20=0.40	1×0.20=0.20	2	13
LCe	4×0.10=0.40	3×0.10=0.30	2×0.20=0.20	1×0.10=0.10	1	17
CoIa	4×0.49=1.96	3×0.49=1.47	2×0.49=0.98	1×0.49=0.49	4.9	2
CoIb	4×0.39=1.56	3×0.39=1.17	2×0.39=0.78	1×0.39=0.39	3.9	6
CoIc	4×0.29=1.16	3×0.29=0.87	2×0.29=0.58	1×0.29=0.29	2.9	10
CoId	4×0.19=0.76	3×0.19=0.57	2×0.19=0.38	1×0.19=0.19	1.9	14
CoIe	4×0.09=0.36	3×0.09=0.27	2×0.09=0.18	1×0.09=0.09	0.9	18
TLOa	4×0.48=1.92	3×0.48=1.44	2×0.48=0.96	1×0.48=0.48	4.8	3
TLOb	4×0.38=1.52	3×0.38=1.14	2×0.38=0.78	1×0.38=0.38	3.82	7
TLOc	4×0.28=1.12	3×0.28=0.84	2×0.28=0.56	1×0.28=0.28	2.8	11
TLOd	4×0.18=0.72	3×0.18=0.54	2×0.18=0.36	1×0.18=0.18	1.8	15
TLOe	4×0.08=0.32	3×0.08=0.24	2×0.08=0.16	1×0.08=0.08	0.8	19
LCMa	4×0.47=1.88	3×0.47=1.41	2×0.47=0.94	1×0.47=0.47	4.7	4
LCMb	4×0.37=1.48	3×0.37=1.11	2×0.37=0.74	1×0.37=0.37	3.7	8
LCMc	4×0.27=1.08	3×0.27=0.81	2×0.27=0.54	1×0.27=0.27	2.7	12
LCMe	4×0.17=0.68	3×0.17=0.51	2×0.17=0.34	1×0.17=0.17	1.7	16
LCMe	4×0.07=0.28	3×0.07=0.21	2×0.07=0.14	1×0.07=0.07	0.7	20
	22.8	17.1	11.42	5.7	57.02	

*DP=Dominated Parameters for Influencing Solar Energy Policy in Remote Rural Areas in Bangladesh

*MIP= Minor Influencing Parameters for Developing Solar Energy Policy at Rural Areas in Bangladesh

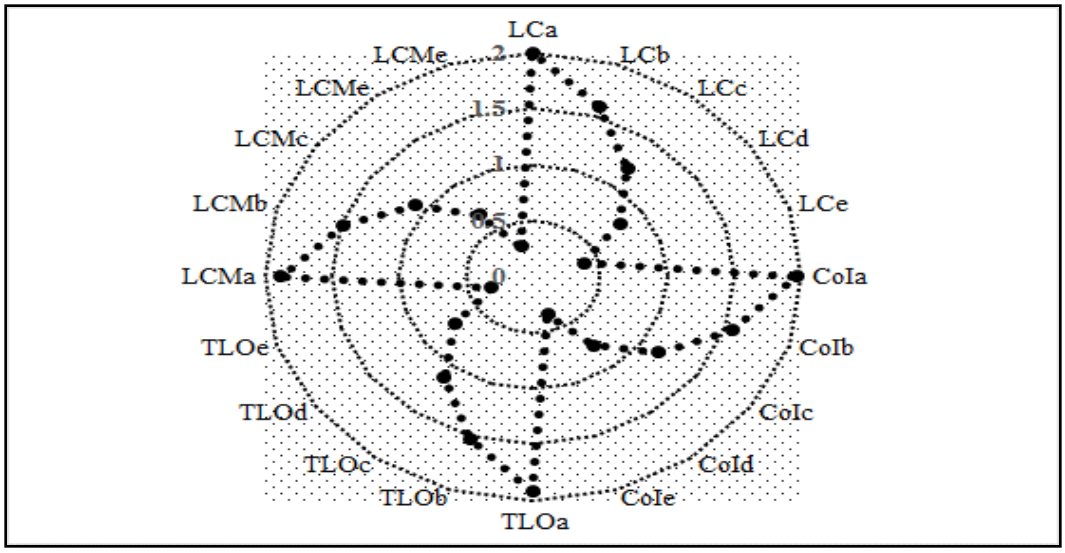

Fig. 4: Local Contexts (LC) of Influencing the Solar Home System (SHS) Installation

The Fig. 4 shows that the MIP= Minor Influencing Parameters in developed Community Response to Solar Energy Approach (CReSEA) model for Developing Solar Energy Policy at Rural Areas in Bangladesh have been influencing the model significantly. If the DP=Dominated Parameters for Influencing Solar Energy Policy in Remote Rural Areas in Bangladesh of CReSEA model are worked well then the solar energy utilizations will be increased in the study area. It is observed that MIP= Minor Influencing Parameters i.e. LCa has the rank 1, CoI has the rank 2, TLOa has the rank 3 and similarly LCMa rank is 4. It means that these four minor influencing parameters of the CReSEA model have the significant impact to develop the solar energy in the study area as well as rural Bangladesh (Fig. 5).

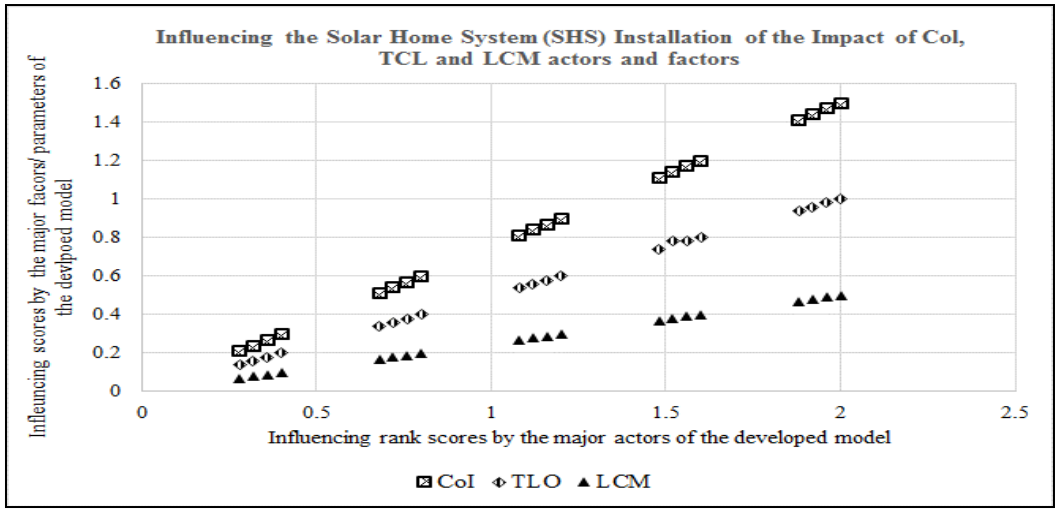

Fig. 5: Influencing the Solar Home System (SHS) Installation of the Impact of CoI, TCL and LCM actors and factors

3.4 Implication of DPSIR Model for Developing Solar Energy Policy Options

The reason for which most of the solar panel plans don't work out in the country is because of the poor policies regarding the energy sources. Even though Bangladesh is a developing country, it still vastly depends on non-renewable sources of energy. Because of this the rural area also struggles vastly. The most primary way of supplying electricity to citizens here is the grid system. While it is very efficient to use in urbanized areas or industrialized areas, it is not very efficient in rural areas. Many people depend on energy from generators which is also very expensive and not everyone can afford. Solar energy although throughout the years is very well known in different parts of Bangladesh, but it's not completely known yet. It is often seen in hilly areas where the sunlight is vast, and people use small PV panels which is installed on top of their houses. It generates electricity for them to use throughout the day, and if they have a battery, they can also save the electricity produced for later use at night. The following DPSIR model is explained in details below:

Drivers: The reason why there is a prospect of solar panels in rural Bangladesh is because firstly, it will boost up the economy for the country by producing more electricity and making development without having to invest non-renewable resources or installing grids. It is also sustainable and clean energy, which is very important to use at this point given the world is facing an energy crisis and massive climate change issues.

Pressures: Even though it is a good idea, the entire panel depends on the weather (sunlight). Because of climate change there are irregularities in the weather which could cause problems. Resources are next to unavailable in rural areas so maintenance of these panels could become really tough. Low maintenance can lead to fires which could become very fatal and deadly.

State: It is always a benefit for the state as electricity will be produced. Which can also be stored for later use. People in rural areas can now have access to more appliances like fridges and televisions.

Impact: The electricity generated in the area can help in development of the public health and education system. Children can now learn more and better treatment can be given to the people as well.

Response: The government has to work on policies that can mandate these more in rural areas and also conduct awareness campaigns and easy loan campaigns so that people can afford this.

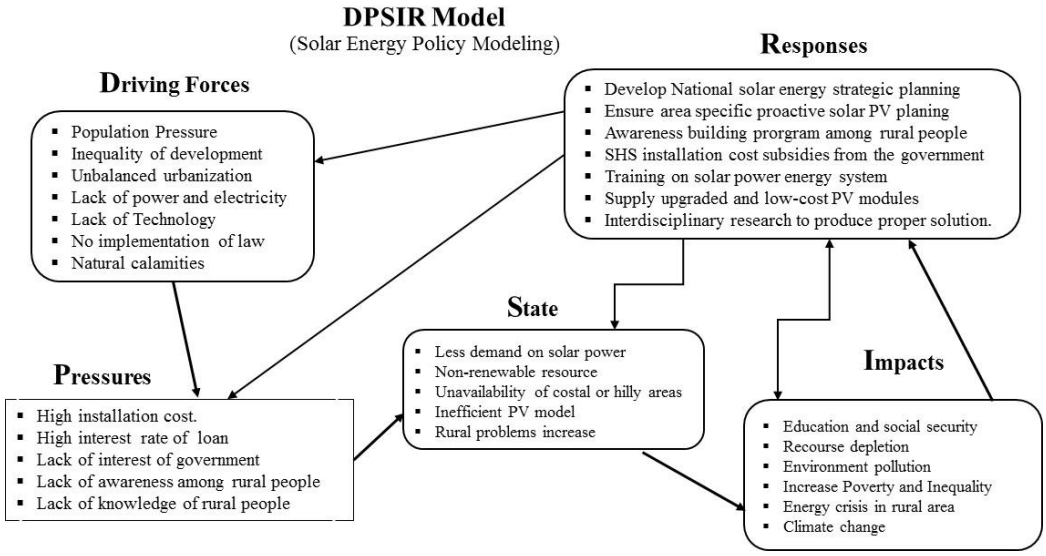

Fig. 6: Causes and consequences of social home system implementation at the rural areas in Bangladesh

One other problem that Bangladesh may have while using solar energy, is the monsoon season or irregular weather conditions due to climate change. Although, for the time being sunlight hasn't been scarce on this part not much problems were faced regarding this issue as of yet.

3.5 Implications of SWOT Analysis for solar energy utilizations in rural area

This SWOT Analysis was prepared by me and below is the given analysis in descriptive form:

Strengths

- The citizens in rural areas can install a solar panel (PV) at their home without much hassle. They need to make a one-time investment which is all they need. There are no extra charges to generate the panel, all they need is the sunlight which they will be getting in an abundance amount from the nature. In addition to that, if they purchase a battery as well, they can store the extra energy generated and use it later for other activities.
- Because this is a renewable energy source and is generated by resources from the environment itself, it doesn't release any harmful substance or any other sort of harmful gases in the atmosphere. Hence, we can say that it is environment friendly.
- Installing solar panels in rural areas would mean generating electricity in those areas. The people can now have proper lighting, fridge and television. There will be a development in the public health, education systems there as well.

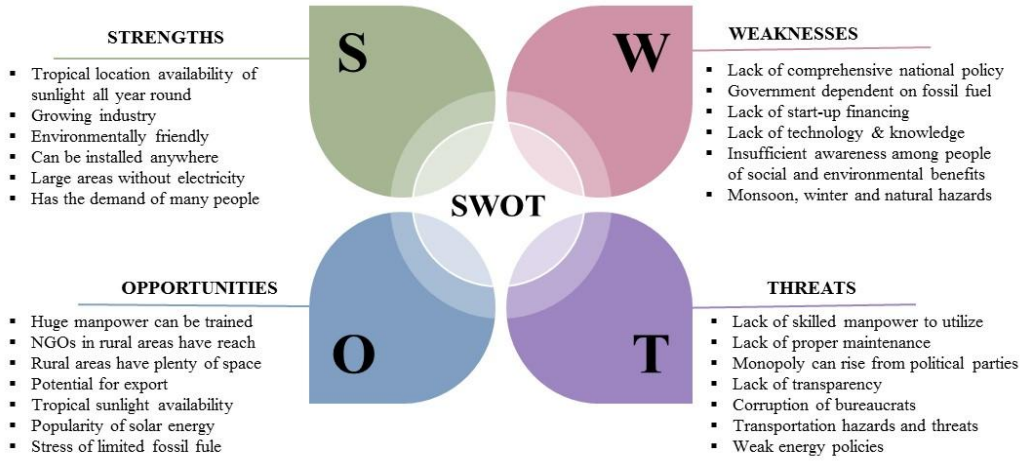

Fig. 7: Various procedures and planning to solve the existing situation of solar energy issues in Bangladesh.

Weakness

- Because of the one-time high installation fee, the farmers who struggle to make day's meet might not find it feasible to invest on a solar panel. Although in some rural areas, there are banks and NGOs that offer micro and macro loans, but it's not the case for most areas in the country and not everyone wants to take a loan regardless of the low interest.
- This is a fairly new technology and not yet common. There are a very few companies that install these panels but they only have limited resources and are not available everywhere especially out of the city in rural areas. This is a major factor because people living in rural areas have little to no scope of maintenance.
- It is heavily dependent on the weather. If there is no sunlight, it means there will be no electricity. With the changing climate around the world right now, this could play a major factor.

Opportunities

- If installed there is of course more development scope for people. For example: With better lighting children will be able to study at home at night; which is a development for the future of that place.
- If solar panel companies trained and hired people in the rural areas to fix, install and maintain these panels; it would mean more job opportunities will be created for the people of the town.
- All of these actions will lead to more economic development for the country.

Threats

- There is only threat to all of this and that is the fear of a disaster. Low maintenance and mishandling of these panels could lead to accidental fires which could be very deadly.

3.6 Validation of Community Response to Solar Energy Approach (CReSEA) model

There are several uncertainties are responsible to validate the Community Response to Solar Energy Approach (CReSEA) model. Rural areas are home to most of the poor. Also, the nature and behaviours of rural inhabitants are very complex and fragile. There will be many uncertainties from the rural environment and socio-economic conditions to validate this community response to the Solar Energy Approach (CReSEA) model. It is very difficult to validate the model because the rural areas are characterized by governance gaps and informality, gender inequalities in rural areas are pervasive. Underemployment is widespread and incomes are generally low in the rural areas in Bangladesh. Also, access to social protection is extremely limited and rural peoples and workers are often vulnerable that is the reason to validate the model is a complex issue. But in order to validate this model, a feasibility study has to be done in three different case study areas through different pilot projects. But due to lack of budget and time, this Community Response to Solar Energy Approach (CReSEA) model has been theoretically validated, but its practical side has not been tested through the pilot project. The practicality and accuracy of this model can be verified in further research.

4. Discussion

Although Solar Panels have a big scope in rural areas of Bangladesh, there are a lot of factors and challenges that needs to be considered (Rahman and Ahmad, 2013). The biggest one being the contribution from the government's side through making and strictly enforcing policies that would keep the welfare of the stakeholders in mind (Pirard, 2012). People living in the rural areas don't get much access to many information and facilities due to where they live and the government not being able to creating accessibility for them. Hence, more awareness could create more development. The people knowing about their options would help them to decide what they want to do and if they would like to invest in a solar pane (Palm and Eriksson, 2018). A solar panel will generate clean energy for them, which would improve their quality of life and we will also see a significant amount of development happening.

The developed Community Response of Solar Energy Approach (CReSEA) model can predict that some major and minor actors and factors are responsible to enhance the solar energy in the remote rural areas especially in the case studies of this research. According to the DPSIR framework and SWOT analysis it reveals that there are many significant strengths and opportunities are existing in Bangladesh to generate the solar energy by utilizing solar home system appropriately (Biswas and Iqbal, 2018). There is also so many prospects of solar panels in rural Bangladesh is because firstly, it will boost up the economy for the country by producing more electricity and making development without having to invest non-renewable resources or installing grids (Khan, 2019a). Though many challenges, weakness and threats are available to install the solar home system in the rural areas but it is possible to overcome all the hurdles through developing some efficient policy and models. The developed Community Response of Solar Energy Approach (CReSEA) model would be very helpful to increase the techniques of operators and users of solar home systems in the rural areas in Bangladesh.

The important barriers of the implementation of solar home systems are high installation cost. Most of the inhabitants of remote rural household's heads are very poor. They cannot afford the solar home installation costs. At average cost of solar home installation in Bangladesh 7,000 BDT to 18,000 BDT so that it is quite difficult to bear this cost by the poor households of the study area. If the government provides some incentives or bear the solar home installations cost most of the families will be agreed to take the solar systems in the rural areas. Considering the future energy crisis in the country the government, NGOs and the private sectors can work together with hand in hand to give priority to enhance the solar energy for producing electricity to solve the future power crisis in Bangladesh. Solar energy although throughout the years is very well known in different parts of Bangladesh, but it's not completely known yet. It is often seen in hilly areas where the sunlight is vast, and people use small PV panels which is installed on top of their houses (Khan et al., 2019b). It generates electricity for them to use throughout the day, and if they have a battery, they can also save the electricity produced for later use at night. One other problem that Bangladesh may have while using solar energy, is the monsoon season or irregular weather conditions due to climate change. Although, for the time being sunlight hasn't been scarce on this part not much problems were faced regarding this issue as of yet.

5. Conclusion

Bangladesh being in the most proper climatic position for solar energy, is perfect for the rural areas. The situation in the rural areas of the countries is alright but not in the best conditions. There are still many areas that do not have electricity access. The majority of the population living in these rural areas are farmers or agricultural workers. Electricity is very essential as it will change their lives for the better and will also help them to utilize many other machineries related to farming or agricultural purpose which could make their lives easier. PV panels are perfect for these areas however, they have are expensive to install. Although, the installation process is a onetime investment; majority of the population cannot afford it. One other problem would be, since it is not a common source that has been used, the maintenance will be hard if the company doesn't provide proper services or guidance. Government needs to step in and create policies that promote solar energy in rural areas of the country. Solar Panel installing companies in affiliation with the government could do campaigns around the rural areas promoting solar panels and micro and macro loans to purchase them. Solar Panel companies should also make maintenance facilities available in rural areas. One way to achieve this is to train people from the community. This would mean the creation of more jobs hence economic development. A purchase of battery should always be encouraged with the panels so that everyone can store the energy for later use. The developed CReSEA model would be the pathways to improve the solar energy status in the rural areas in Bangladesh.

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