Off-grid electrification scenarios for rural electrification in Myanmar

H. Sasaki*[1,2], M. Seino[2], N. Hashimoto[2] and I. Sakata[1]

[1]Innovation Policy Research Center, Institute of Engineering Innovation, School of Engineering, The University of Tokyo, Tokyo, Japan
e–mail: sasaki@pari.u-tokyo.ac.jp, isakata@ipr-ctr.t.u-tokyo.ac.jp

[2]Policy Alternatives Research Institute, The University of Tokyo, Tokyo, Japan
e–mail: seinom2038@yahoo.co.jp, hashisan2001@yahoo.co.jp

ABSTRACT

Myanmar is expected to improve its energy access rapidly. Sustainable Energy for All (SE4ALL) has set a goal of ensuring modern energy services for all countries. Myanmar has all the characteristics of a country that can benefit greatly from the priorities of this initiative.

The national electric grid extends to serve only a small percentage of the population. Rural electrification is crucially important for improving the national electrification rate. This report presents discussion of a rural electrification scenario for feasible rural electrification alternatives in Myanmar.

Some donors are carrying out a proposed master plan related to electrification. Plans being produced by development partners, however, underestimate their study resulted to have few proportion of micro-grids and distributed generation. Herein, we assess alternative scenarios in which such microgrids play an important role.

For this study, we conducted demand projection, cost estimation, and scenario preparation for a rural electrification plan. We studied the current conditions of electrical access and made a demand projection. For cost estimation, we estimated the net present cost for rural electrification for micro-grids. For optimization, we used HOMER software, which can compare multiple technical specifications and economical conditions and which can produce models for dynamic behaviors and lifecycle costs of power sources, etc., which constitute the system.

Based on these results, we assessed each scenario and proposed policy alternatives for the rural electrification in Myanmar. Securing great amounts of funding or lowering the target household electrification rate must be considered for the implementation of the electrification plan. Rural electrification necessitates the involvement of private investors for financial and technical reasons. Development of middle-sized hydropower in unelectrified regions is particularly important. Such installations are expected to supply power efficiently to many villages, increasing the electrification rate greatly with the establishment of center core power stations in rural areas.

KEYWORDS

Myanmar; Rural electrification; Off-grid; Developing country; Alternative scenarios; Optimization; HOMER;

INTRODUCTION

Myanmar, which borders China, Laos, Thailand, Bangladesh, and India, is located in the western part of the Indochina Peninsula. Although the country has rich energy resources, it is among the energy-poorest countries in the world. Sustainable Energy for All (SE4ALL), a global framework launched by the United Nations and coordinated by 15 agencies, has set a goal of ensuring modern energy services for all countries. In fact, the country has all the characteristics of a country that can benefit greatly from the priorities of this initiative.

In Myanmar, the national electric grid reaches only a small percentage of the population. Rural electrification is crucially important for improving the national electrification rate. Particularly in recent years, the supply of power infrastructure has been unable to meet demand amid rapid democratization and economic reform. On the other hand, rural electrification is crucially important for improving poverty reduction. This paper presents a discussion of a rural electrification scenario for feasible rural electrification alternatives in this country.

In 2013, the jurisdiction for rural electrification in Myanmar was transferred from the Ministry of Industry (MOI) to the Ministry of Livestock, Fishery and Rural Development (MLFRD), which now acts as the central agency managing regional electrification. Regarding off-grid electrification undertaken as specific rural electric power development, under the MLFRD, regional development bureaus are newly electrifying 20,000 villages during a five-year plan (2011/2012 – 2015/2016) that includes an electrification plan based on a mini-grid consisting of renewable energy resources. Therefore, at the end of the plan, 42,441 villages will be electrified (village electrification rate of 65.4%). For on-grid electrification however, the Ministry of Electric Power (MOEP) is planning the promotion of electrification by extending existing power transmission lines. Mutual alignment of on-grid and off-grid electrification plans is expected to achieve more efficient rural electric power development.

A blueprint of future energy planning in Myanmar is now being prepared with the support of three aid agencies. The Asia Development Bank (ADB) is conducting a master plan survey of all energy including electric power. The Japan International Cooperation Agency (JICA) conducted a master plan survey of electric power development plans and transmission line installation plans specializing in electric power (June 2013 – November 2014). However, the World Bank (WB) has conducted a rural electrification master plan survey that emphasizes grid extension. The three surveys are directed at different objectives and are clearly demarcated, but the survey results must be linked and coordinated as an overall survey. Particularly the rural electrification plan that WB proposes will constitute the base of national rural electrification. Its positioning must be considered carefully from a broad perspective of overall energy planning. Furthermore, it is necessary for the supply of electricity to rural regions planned based on the electric power master plan surveys to meet electrification demand, and for the feasibility of electrification plans to be verified. Therefore, outlines and results of the three surveys were summarized. Simultaneously they were roughly compared.

Table 1 is a comparative table of outlines of the three surveys. To resolve difficulties related to the overall domestic energy sector, the Myanmar Government established the National Energy Management Committee (NEMC) to prepare a national energy plan related to oil, gas, coal, and electric power based on its national energy policy. It is conducting a master plan survey of energy with support by the ADB. Its energy policies were being summarized in Energy Policy (Draft) with support by the ADB in May 2015. The electric power master plan survey conducted by JICA assessed the electric power supply plans to meet the demand predicted by 2030. The survey prepared some scenarios for a power development plan and transmission line installation plan, and identified and analyzed challenges to the implementation of the plans. Then WB conducted a master plan survey specialized for rural electrification. The survey considered a plan for electrification by grid extension and proposed a rural electrification plan to achieve a 100% household electrification rate by 2030.

Table 1. Outline comparison of three electrical power development studies

Donor	ADB	JICA	WB
Coverage	Energy Master Plan	National Electricity Master Plan	National Electrification Plan
Main focus	Primary energy	Power generation and transmission grid plan	Rural electrification plan by distribution grid extension and mini-grid/ off-grid plan
Time frame	Up to 2035	Up to 2030	Up to 2030
Main counterpart	NEMC/MOE	MOEP	MOEP/MLFRD
Energy demand forecast	Primary energy demand forecast (by sector/ energy form), electricity demand forecast using a bottom-up approach	Overall electricity demand forecast (industrial and non-industrial) based on GDP growth rate and electricity	Electricity demand forecast for new residential connection
Method of Evaluation	Energy demand/ supply/ fund procurements were planned against the future economic prospect using a least-cost approach.	LRMC for generation and transmission of each scenario was calculated and compared.	Economic comparison between grid extension and mini-grid/ off-grid plan was made in each province. LRMC for grid extension nationwide was calculated.
Final output	Optimal primary energy development plan (gas/ oil/ coal/ hydro/ biomass/ solar/ others)	Three scenarios of generation (hydro/thermal/RE) and transmission plan were compared in terms of energy security/ cost/ environment consideration.	Grid extension plan and mini-grid (diesel)/ off-grid (SHS) were planned in each province.
Planned infrastructure	Energy infrastructure required (power plant/refinery)	Power generation plant and transmission line	Grid extension plan and mini-grid/ off-grid plan

Descriptions regarding access to electricity from the existing grid can be found in reports from ADB, JICA, and WB, which are summarized in Table 2. These reports refer to different years and not only contain differences in data relating to the number of electrified households and percentage electrified, but also differences in terms of basic data regarding the population and number of households. The JICA report refers to the number of villages with electricity from either the national grid or other sources, but does not give the number or a percentage of households electrified. The WB (EI) does not discuss this in terms of the percent of households electrified. The Castalia report gives the figure of 2.3 million electrified households (< 30%), and according to an ADB report (ADB, December 2014) 2.74 million households were supplied with electricity from the existing grid in 2014.

Table 2. Descriptions in three studies of access to electricity via the existing power grid

Description	ADB	JICA	WB
National basic data			
Population	60,976,000 (in 2012)	Not available	54,320,000 (in 2011)
Households	14,233,196 (in 2014)	Not available	9,190,000 (in 2011)
No. of Villages		64,917 (in 2013)	
Electrified			
Population			
Households	2,742,169 (in 2014)		About 2.3 million
No. of Villages		4,785 (in 2013)	
Electrification rate	19% (in 2014)		Less than 30%

Source: Asian Development Bank and the Myanmar Ministry of Energy (2014)[1], CASTALIA (2014) [2], Earth Institute, Sustainable Engineering Lab Colombia University (2014) [4], JICA (2015) [7],

The government aims to achieve a 100% household electrification rate by 2030 through the National Electrification Plan (NEP) (Castalia, 2014) [2]. When enacting a rural electrification plan, the most economical and efficient electrification method is on-grid electrification. Grid expansion is based on the premise that they can secure enough supply to meet demand. Since they don't have integrity plans between supply and demand, they cannot supply 100% electrification rate by grid expansion. In this paper, we specifically examine off-grid electrification to consider how off-grid electrification can be promoted. Along with the on-grid electrification, we identify challenges to rural electrification development, and discuss countermeasures to overcome these challenges, concluding with a summary of policy recommendations for rural electrification.

METHODOLOGY

This research presents scenarios for rural electrification in Myanmar. The scenarios deal with off-grid electrification. Each scenario is analyzed under various study conditions. Challenges to rural electric power developed by off-grid electrification are identified. Moreover, countermeasures to overcome the challenges are considered. Figure 1 presents specific procedures for preparing a scenario.

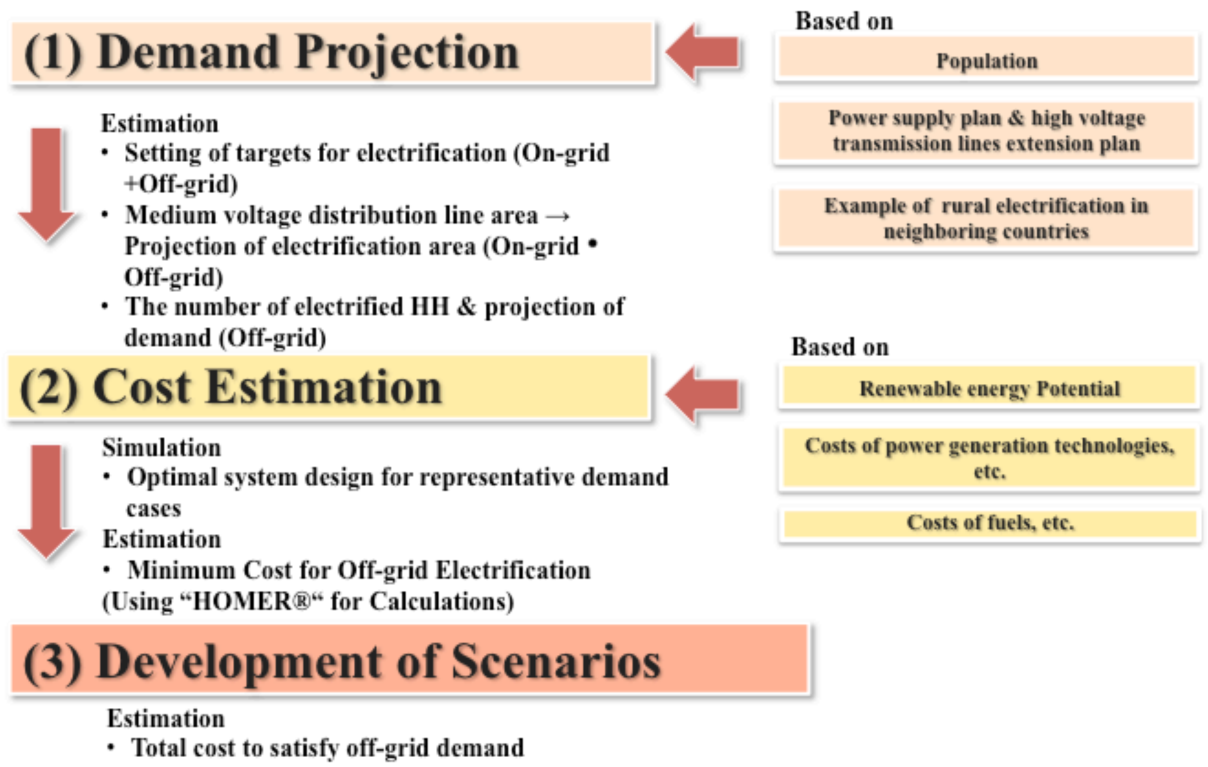

Figure 1. Process of Scenario Making

A common condition for each scenario is achieving the 100% target household electrification by 2030. The preparation procedure involves three principal pillars. The first is Demand Projection, which is a prediction of demand in 2030 in un-electrified regions. To predict demand, electrification demand in regions not covered by grid electrification was predicted independently based on fundamental public data used for the past three surveys (ADB, JICA, WB). Regarding grid electrification, the range of grid electrification predicted according to electric power supply (MOEP case, JICA high case and JICA low case) for regions in the JICA master plan survey was determined. The remainder will be off-grid electrification. At the next stage of Cost Estimation, the micro-grid configuration that will be applied to off-grid electrification was proposed. The power source installation costs necessary to construct each micro-grid were calculated along with operating costs until 2030. Then, based on these calculated values, the total net present cost necessary to build out the infrastructure needed to achieve rural electrification was computed. Finally, at stage three, Development Scenarios, the percentage of the model micro-grid was predicted separately for each state. Scenarios were presented with three axes: grid power supply level, power demand level by household, and photovoltaic power production technology trends.

The method used for the demand forecast for rural electrification is as follows. We assume that demand forecast for rural electrification is about the demand of households for achieving the goal of 100% household electrification nationwide by 2030. Give grid electrification high priority, areas that do not reach 100% will be supplemented by off-grid electrification. Based on these assumption, we estimate annual power demand per household, and out of the demand forecast (equals supply capacity) allocated to each State/Region (based on the demand forecast of JICA high and low cases, and the MOEP case) calculate the number of households that can be electrified with the portion of the power demand allocated for households (40% of the total).

MOEP of Myanmar started the project with the goal of 100% grid electrification of households by 2030 based on the National Electrification Plan of the WB (Least-Cost Geospatial Electrification Planning Results)

In the National Electrification Plan of WB, the annual energy demand for each newly electrified household (no distinction between urban and rural) is set at 1000 kWh, but the national average for annual energy demand per household in Myanmar is about 1300 kWh, as of 2013. Therefore, for the basic case in this UT study, it is assumed that the annual demand per household is 2000 kWh for urban households, and 1000 kWh for rural households. A sensitivity analysis was conducted against several values of annual demand per household and allocated demand.

The Hybrid Optimization Model for Electric Renewable (HOMER) is used to calculate the construction cost of a unit micro-grid. HOMER is software developed by the U.S. National Renewable Energy Laboratory (NREL) to design micro-grid systems and compare power technologies easily. The design conditions of a microgrid system change greatly because of uncertainty such as the load size of demand location and fuel costs. Similar to renewable energy, by adding elements with uncertainty and seasonality, its design and analysis has become more complex. HOMER is simulation software developed to design micro-grid systems with such complexity.

There are many examples of HOMER in use. As an example of typical rural electrification in Saudi Arabia, Shaahid and El-Amin (2009) and others calculated the techno-economic optimization with the implementation of a solar power system, diesel generator, and configuration of batteries, with Rawdhat Bin Habbas village as the subject using HOMER [11]. Gerry (2013) implemented optimum calculations using HOMER as a case study to introduce a system that can be established with elements such as solar power generation, wind power generation, small hydropower generation, biogas power generation, batteries, etc., in remote and rural villages in India [5]. Kanase-Patil et al. (2010) proposed four scenarios for each combination of power configuration in seven villages in Almora district, India [8]. The author calculated the minimum cost of electricity (COE) using LINGO based on the actual data, and used HOMER to examine its validity as a comparison subject. Sanjoy Kumar Nandi and Himangshu Ranjan Ghosh (2010) used HOMER to examine the feasibility of a hybrid power source consisting of wind power, solar power, and batteries in Bangladesh [9]. As such, as an implementation simulation of a dispersed power system in rural electrification in developing countries, there are numerous examples of the application of this software.

HOMER runs multiple calculations with a necessary and sufficient power configuration for a load set as the input value by a user, and the unit number of each power type, as realistic solutions. In addition, the life-cycle cost is an extremely useful index for discussing multiple system configurations from the perspective of economic rationality. When a system is being introduced, decisions are often made simply based on the short-sighted notion of initial cost. However, a cost effective structure must be examined by making determinations from the mid- to long-term perspective. In this calculation, the project period was set to 2030. The total cost up to that date is used for the determination of the system configuration. The life-cycle cost based on HOMER is represented by the total net present cost (NPC), which contains all the cost throughout the entire project period. Specifically, this is the cost that includes all costs such as the initial investment cost of elements that constitute the said system during the entire project period (everything including power sources, batteries, etc.), operating cost, replacement cost, fuel cost, and power purchase cost from the grid.

In the simulation, the system connection and off-grid system are modeled. Multiple combinations of the solar power generation module, small hydro, biomass, and power sources, etc., are compared. At the same time, the power load simulation for both DC and AC are conducted. HOMER simulates renewable energy power that is usable per hour throughout the year. By comparing the power load at that time, the optimal configuration is proposed along with the excess and deficiency of supplied power. HOMER calculates the total NPC as a life-cycle cost of the entire system. The results of optimization calculation are made based on this total NPC. The calculation equation of the total NPC is shown below.

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i,N)} \tag{1}$$

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{2}$$

$C_{\mathrm{ann,tot}}$ is the total annualized cost (USD/year), including capital cost, replacement cost, annual operating and maintenance cost, and fuel cost.

In the optimization process, HOMER simulates multiple system configurations, and searches for the configuration with the lowest life-cycle cost. In addition, by conducting sensitivity analysis, under multiple different input conditions, the optimal result for each condition can be presented. Normally, the potential of renewable energy and specifications of technologies change moment-by-moment depending on the economy, society, and technology. Some boundary conditions are difficult to predict, but there are many for which trends can be assumed. For example, the efficiency of many power sources is assumed to improve with technological progress. Therefore, continuing to use an older generation of facilities would create a negative legacy. In many cases, previous-generation facilities suffer failures, and obtaining spare parts is difficult, incurring high maintenance costs. In this paper, sensitivity analysis is conducted for a solar power generation system and lithium ion batteries by considering multipliers of implementation cost, replacement cost, and operating cost as sensitivity variables. Details of the results from the sensitivity analysis are shown by sensitivity analysis of the scenario for rural electrification.

Load profile

We classified the size of unit micro-grids into 100 households, 300 households, and 1,000 households. Next, for each household size classification, the demand level per family was assumed to be small (400 kWh/HH) or high (1,000 kWh/HH). Based on these classifications, the six cases of assumed demand for the micro-grid are shown in Table 3.

Table 3. Assumed micro-grids (demand and size)

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
[kwh/HH]	400	400	400	1,000	1,000	1,000
peak [W/HH]	120	120	120	180	180	180
No. of HH / [micro-grid]	100	300	1,000	100	300	1,000
peak [kW / micro-grid]	12	36	120	18	54	180

Type of microgrid

In this paper, to actualize the rural electrification, we consider three types of micro-grid configuration. One of these three micro-grid configurations is a micro-grid that uses solar power and biomass power as the power source. This micro-grid is called the “PV and biogas-oriented micro-grid.” Solar power generation is a power source that is expected to be successful as an off-grid power source in developing countries. There is paddy production, which has potential for the reduction of implementation costs and biomass in rural parts of Myanmar. With the introduction of rice husk power generation, which is a type of biomass power generation, electrification that uses this paddy production as fuel is expected to contribute to the rural electrification of Myanmar. In addition, the PV and biogas-oriented micro-grid has converters and a storage battery as components. Because the production potential of biomass differs among states, the cost for the PV and biogas-oriented micro-grids is calculated for each state.

Next, as a micro-grid that handles all demands by hydropower, the “hydropower-oriented micro-grid” is considered. Electrification by micro-hydropower in developing countries has a positive track record as a method of rural electrification. Particularly, the potential hydropower in Myanmar is approximately 48.5 GW. Tributaries of the Ayeyarwady River, Sittang River and Salween River extend throughout the country. Consequently, it is regarded as an effective method of electrification. In this study, we assumed a micro-grid for which the supply can be provided by micro-hydropower only. We defined it as the “hydropower-oriented micro-grid.”

In this study, as a micro-grid that uses a diesel generator as the power source, we consider the “diesel-oriented micro-grid.” Diesel generators are widely used as a method of rural electrification, and on the other, such generators incur many challenges. Diesel generators also present the issue of high economic uncertainty because of fuel price fluctuations. Although the development of a clean diesel technology is progressing, the fact that fuel costs account for most the total cost is unchanged. Consequently, as a method of rural electrification, economic rationality is lower than the current diesel power generation. However, because of ease of implementation arising from its compact and portable nature, it is used as the basic power source for many micro-grids. This study considers only micro-grids for which the only method of power supply is a diesel generator, and defined them as a “diesel-oriented micro-grid.”

Recent developments of renewable energy technology are remarkable. A marked reduction in technical costs is expected in the future. The rapid development of solar power generating panels and lithium ion batteries is particularly noteworthy. Therefore, we conducted sensitivity analysis based on the price of solar power generation and lithium ion batteries expected in 2030. Candelise et al. (2012) reported future forecasts of solar power generation. The price of solar power generation in 2030 is expected to be 1,250 USD/kWp [3]. Nykvist and Nilsson (2015) reported a price forecast of lithium ion batteries. The figure shows that reduction to half that of the previous price is possible [10]. Based on the discussion presented above, the cost of solar power generation and lithium ion batteries is expected to be about half that of the 2015 level.

Potential of renewable energy and specifications of power configurations

We present explanations of the potential of renewable energy and specifications of power configurations that are prerequisite conditions for cost estimation.

Photovoltaic (PV)

The Myanmar Electric Power Enterprise (MEPE) measures the amount of sunlight in areas where it is 5 kWh/m^2/day or higher during the dry season. Yee et al. (2008) applied the annual amount of sunlight from the following 11 locations as worst-case scenarios [12]. The amount of sunlight in this analysis was taken from Yangon for uniformity of the conditions. The amount of sunlight in Yangon is 3.5 kWh/m^2/day – 6.4 kWh/m^2/day. The mean value is 4.49 kWh/m^2/day. During June–October, it is the rainy season. The amount of sunlight is low. HOMER can calculate the clearness index automatically if the amount of sunlight is input.

Biomass

Power or heat is generated from many types of biomass (e.g., wood waste, agricultural residue, animal waste, energy crops). In this study, we consider biomass power generation using rice husks as a resource because they are easy to obtain in Myanmar. Biomass power generation is unique compared to other power sources in the following two respects: 1)

Biomass resources are dependent on human efforts such as harvest, transportation, and storage. Consequently, despite seasonal fluctuations, resources are never completely interrupted. 2) Biomass feedstock can be converted to gaseous and liquid fuels.Paddy production [kg/day] per day for each micro-grid size considered in this study, calculated based on the above values, is shown in Table 4.

Table 4. Daily feedstock [kg/day] for each microgrid size

	100HH in micro-grid:			**300HH in micro-grid:**			**1,000HH in micro-grid:**		
State	Monsoon	Summer	Total	Monsoon	Summer	Total	Monsoon	Summer	Total
Kayin	133	40	172	398	119	516	1,325	396	1,722
Sagaing	176	47	223	527	141	668	1,756	469	2,225
Bago	224	32	255	671	95	766	2,235	318	2,553
Magway	83	20	103	250	59	309	833	197	1,030
Mon	175	31	205	524	92	616	1,745	307	2,052
Rakhine	138	3	141	413	9	422	1,377	29	1,406
Shan	157	12	170	472	37	510	1,574	125	1,699
Ayeyarwaddy	270	130	401	810	391	1,202	2,701	1,304	4,005

It is impossible to obtain power by directly inputting rice husks into a generator because they must first be converted to clean biogas. In addition, the removal of tar from rice husks is an important hindrance to implementing biomass power generation.

Since 1995, Myanmar Inventors Cooperative Ltd. (MIC) has solved the issue of tar contained in the gas generated from rice husks. They started commercial production of gasifiers and gas engine-driven generators. By 2000, a total of 109 units of a rice husk gasification engine with 6.17MW(8,280 horsepower) had been installed. The majority of these engines are used as the power source for rice production plants. Based on the line-up of rice-husk gasification power generators by MIC, we used the RH-3 model as a reference to choose 6 kW (3,100 USD) for the unit implementation value as biogas generator specifications. In addition, the lower heating value (LHV) of rice husk power generation is said to be 13.36 MJ/kg (Kanase-Patil et al., 2010) [8]. The optimal gasification efficiency is 65 percent (Jain, 2006) [6].

Hydropower generation

Myanmar possesses embryonated hydropower of approximately 48.5 GW, which is expected to contribute greatly to the promotion of rural electrification. In the field of rural electrification based on small-scale and distributed micro-grid power generation, small-scale hydropower generation of less than 1 MW is regarded as effective.

However, for rivers that are considered appropriate for such small-scale hydropower generation, no appropriate data exist for Myanmar. Therefore, available data from limited information was used to estimate the potential that exists for small-scale hydropower generation and in which area. According to HOMER simulation software, hydropower generation can be modeled that convert the flow rate to electric power with a certain degree of efficiency. The hydropower generation output is obtained using the following equation.

$$P_{hyd} = \rho_{water} g H_{net} Q_{turbine} \eta_{hyd} \tag{3}$$

Therein, η_{hyd} is the efficiency of turbine and generator, ρ_{water} represents the density of water, g signifies gravitational acceleration, H_{net} denotes the net head, and Q_{turbine} is the flow rate through the turbine.

The objective of this analysis is calculation of the costs incurred for rural electrification. Regarding hydropower generation analysis, when there is a demand area corresponding to each case, it is possible to construct a hydropower generation facility having sufficient capacity to meet demand. First, the average river flow is set to 5 m^3/s for each case. Second, the flow in the dry season is set to 0.5 m^3/s. To design a small hydropower station that can supply electricity for the demand of each case, an effective head in the range of 2.0 m and 29.2 m is required. Table 5 shows that the maximum output is calculated if the overall efficiency is regarded as 0.7. The amount of annual power generation [MWh] is calculated as 102.7 MWh for case 1H (smallest supply) and 1,533 MWh for case 6H (largest supply). Generally, the unit price of construction of small-scale hydropower generation is said to be linearly proportional to its scale. It is set to 4,000 USD/kW for these analyses. Yearly operational and management costs are set to about four percent of the capital cost. These are presented in Table 5.

Table 5. Specifications of hydropower generation

	Case 1H	Case 2H	Case 3H	Case 4H	Case 5H	Case 6H
Average river flow[m^3/s]	5.0	5.0	5.0	5.0	5.0	5.0
Flow in dry season [m^3/s]	0.5	0.5	0.5	0.5	0.5	0.5
Maximum water consumption Q [m^3/s]	1.0	1.0	1.0	1.0	1.0	1.0
Power generation effective head H [m]	2.0	5.8	19.5	2.9	8.7	29.2
Overall efficiency(η) (Turbine/generator) [/]	0.7	0.7	0.7	0.7	0.7	0.7
Maximum output: P 9.8HQ$_{\eta}$ [kw]	13.4	40.0	134.0	20.0	60.0	200.0
Maximum output: P 9.8HQ$_{\eta}$ [kw] in dry season	10.1	30.0	100.5	15.0	45.0	150.0
Amount of annual power generation [MWh]	102.7	306.6	1027.1	153.3	459.9	1,533
Unit price for construction [USD/kw]	4,000	4,000	4,000	4,000	4,000	4,000
Capital cost [USD]	53,600	160,000	536,000	80,000	240000	800,000
O&M cost [USD/year]	214	640	2,144	320	960	3,200

RESULTS

Electrification rate of grid and off-grid for each State/Region were calculated in accordance with the presuppositions applied in the three demand-forecast cases (JICA high case, JICA low case, and MOEP case). Table 6 shows grid and off-grid electrification rate in the JICA high case, JICA low case, and MOEP case for urban and rural areas by States/Regions

Table 6. Electrification rate in 2030 in the JICA high case, JICA low case, and MOEP case

State /Region	JICA high case				JICA low case				MOEP case			
	Urban		Rural		Urban		Rural		Urban		Rural	
	Grid	Off-grid	Grid	Off-grid	Grid	Off-grid	Grid	Off-grid	Grid	Off-Grid	Grid	Off-grid
Ayeyarwady	21%	0%	27%	52%	21%	0%	14%	65%	21%	0%	50%	28%
Bago	29%	0%	34%	37%	29%	0%	17%	54%	29%	0%	64%	8%
Chin	17%	2%	72%	9%	17%	2%	72%	9%	17%	2%	72%	9%
Kachin	37%	2%	59%	3%	37%	2%	46%	16%	37%	2%	59%	3%
Kayah	36%	0%	64%	0%	36%	0%	64%	0%	36%	0%	64%	0%
Kayin	21%	1%	36%	42%	21%	1%	22%	56%	21%	1%	61%	16%
Magway	19%	0%	26%	55%	19%	0%	10%	72%	19%	0%	50%	32%
Mandalay	38%	0%	62%	0%	38%	0%	62%	0%	38%	0%	62%	0%
Mon	27%	0%	73%	0%	27%	0%	73%	0%	27%	0%	73%	0%
Rakhine	27%	5%	26%	41%	20%	12%	10%	58%	32%	0%	50%	17%
Sagaing	22%	0%	26%	52%	22%	0%	10%	68%	22%	0%	50%	28%
Shan	36%	33%	26%	4%	30%	40%	10%	21%	48%	21%	31%	0%
Tanintharyi	27%	0%	74%	0%	27%	0%	74%	0%	27%	0%	74%	0%
Yangon	66%	0%	34%	0%	66%	0%	34%	0%	66%	0%	34%	0%

Figure 2 shows the results of calculations of annual electricity demand per household, grid electricity demand (amount supplied), and the distribution factors for household demand under the assumption of 100% grid electrification in these 12 states/regions. With a distribution factor of 40%, achieving 100% household grid electrification with annual household electricity demand of 2000 kWh (urban) and 1000 kWh (rural) requires an expected demand of 5460 MW for all 12 areas. This is expected to be an increase of 2670, 1860, and 700 MW for the JICA low, JICA high, and MOEP cases, respectively). Additionally, to achieve 100% household grid electrification using the expected demand (supply capacity) values of the JICA low, JICA high, and MOEP cases, a need exists to reduce annual electricity demand per urban household to 1000 kWh, rural household to 500 kWh (JICA low case), 1300 and 650 kWh (JICA high case), and 1700 and 850 kWh (MOEP case).

With the aim of achieving 100% grid electrification of households across the country by 2030, MOEP has already begun working on plans for electrification in accordance with the least-cost geospatial electrification planning proposed by the WB (EI). However, it is possible and prudent to evaluate the electrification plan above via this sensitivity analysis.

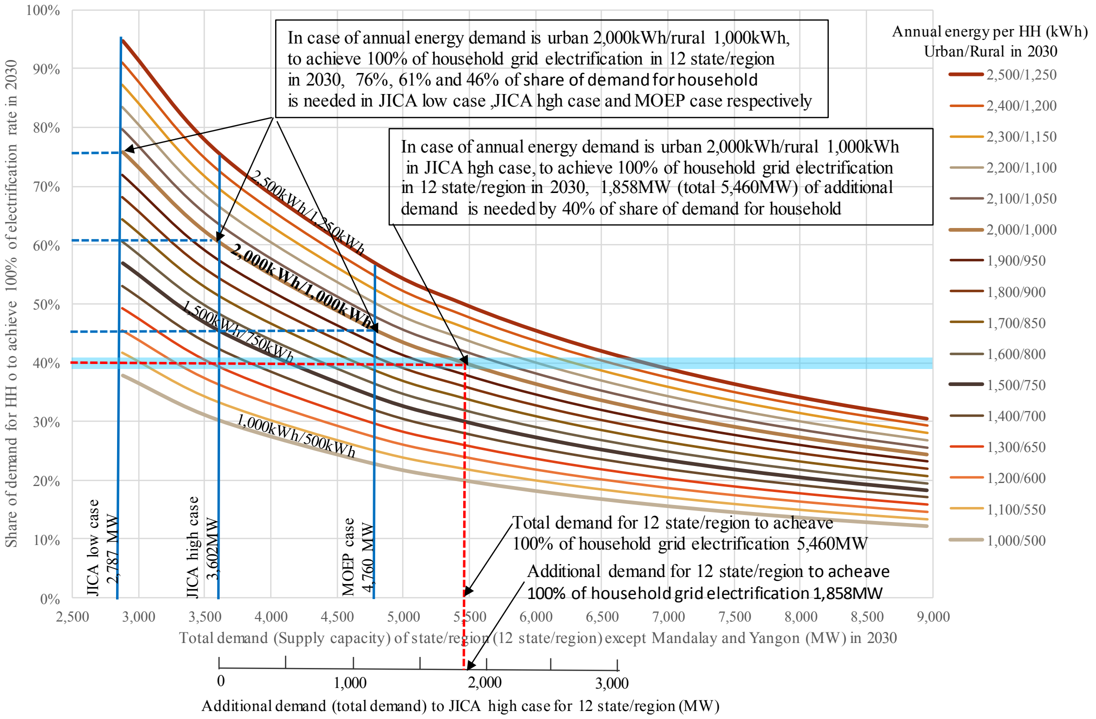

Figure 2. Sensitivity analysis to achieve 100% grid household electrification in 2030

Table 7 and shows Total NPC to 2030 of renewable energy micro-grid. Table 8 present thes basic costs for a renewable energy micro-grid when the costs of solar power generation and lithium ion batteries drop to half that of the previous costs.

Table 7. Total NPC to 2030 of renewable energy micro-grid (Technology multiplier=1.0)

Total NPC USD to 2030	400 kW/HH 100HH /micro-grid	400 kW/HH 300 HH /micro-grid	400 kW/HH 1,000 HH /micro-grid	1,000 kWh/HH 100 HH /micro-grid	1,000 kWh/HH 300 HH /micro-grid	1,000 kWh/HH 1,000 HH /micro-grid
Ayeyarwaddy	94,155	266,471	868,901	243,914	727,631	2,403,520
Bago	128,186	380,504	1,181,552	279,562	845,482	2,765,519
Kayin	141,464	402,520	1,336,042	302,150	888,214	2,956,382

Magwey	168,300	452,274	1,478,099	318,114	945,620	3,150,053
Rakhine	148,417	428,120	1,415,020	310,102	918,555	3,039,102
Sagaing	134,573	371,454	1,236,444	286,288	851,975	2,865,548
Shan	143,175	405,244	1,357,988	302,245	890,556	2,969,003

Table 8. Total NPC to 2030 of renewable energy micro-grid (Technology multiplier=0.5)

Total NPC USD to 2030	400 kW/HH 100HH /microgrid	400 kW/HH 300 HH /microgrid	400 kW/HH 1,000HH /microgrid	1,000 kWh/HH 100 HH /microgrid	1,000 kWh/HH 300HH /microgrid	1,000 kWh/HH 1,000HH /microgrid
Ayeyarwaddy	53,129	149,597	487,415	130,083	386,332	1,272,595
Bago	68,889	205,797	638,011	146,809	443,671	1,451,047
Kayin	75,084	214,354	705,841	157,447	462,158	1,536,612
Magwey	91,124	237,598	776,127	164,881	487,990	1,625,747
Rakhine	78,412	227,534	749,426	161,144	476,601	1,575,591
Sagaing	70,582	201,063	664,845	149,906	445,272	1,495,877
Shan	75,731	216,768	717,466	157,494	463,287	1,542,583

Table 9 shows the basic costs for a hydropower-oriented micro-grid (initial cost, operating cost, and total NPC). Table 10 shows the basic costs for a diesel-oriented micro-grid.

Table 9 Total NPC to 2030 of hydropower-dependent micro-grid

	Case 1H	Case 2H	Case 3H	Case 4H	Case 5H	Case 6H
	400 kW/HH	400 kW/HH	400 kW/HH	1,000 kWh/HH	1,000 kWh/HH	1,000 kWh/HH
	100HH /micro-grid	300HH /micro-grid	1,000HH /micro-grid	100 HH /micro-grid	300HH /micro-grid	1,000HH /micro-grid
Total NPC to 2030 [USD]	50,098	149,548	500,982	74,773	224,320	747,734

Table10 Total NPC to 2030 of diesel-dependent micro-grid

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
	400 kW/HH	400 kW/HH	400 kW/HH	1,000 kWh/HH	1,000 kWh/HH	1,000 kWh/HH
	100HH /micro-grid	300HH /micro-grid	1,000HH /micro-grid	100 HH /micro-grid	300HH /micro-grid	1,000HH /micro-grid
Total NPC to 2030 [USD]	114,693	344,096	988,780	282,283	702,840	2,210,611

Table 11 and Figure show the approximate costs of each scenario.

Table 11. Summary of Net present costs in each scenario (Unit: MUSD)

	Technology multiplier	Annual demand in Households	National demand case	Cost for rural electrification (MUSD)			
				RE oriented	Hydro oriented	Diesel oriented	Total
#1	1.0	400 kWh/HH	MOEP	1,233	41	286	1,560
#2			JICA high	2,184	45	478	2,708

#3			JICA low	3,307	74	636	4,018
#4		1,000 kWh/HH	MOEP	2,896	61	700	3,657
#5			JICA high	4,792	68	1,163	6,023
#6			JICA low	7,212	111	1,536	8,859
#7	0.5	400 kWh/HH	MOEP	679	41	286	1,006
#8			JICA high	1,183	45	478	1,707
#9			JICA low	1,788	74	636	2,499
#10		1,000 kWh/HH	MOEP	1,529	61	700	2,290
#11			JICA high	2,515	68	1,163	3,745
#12			JICA low	3,782	111	1,536	5,430

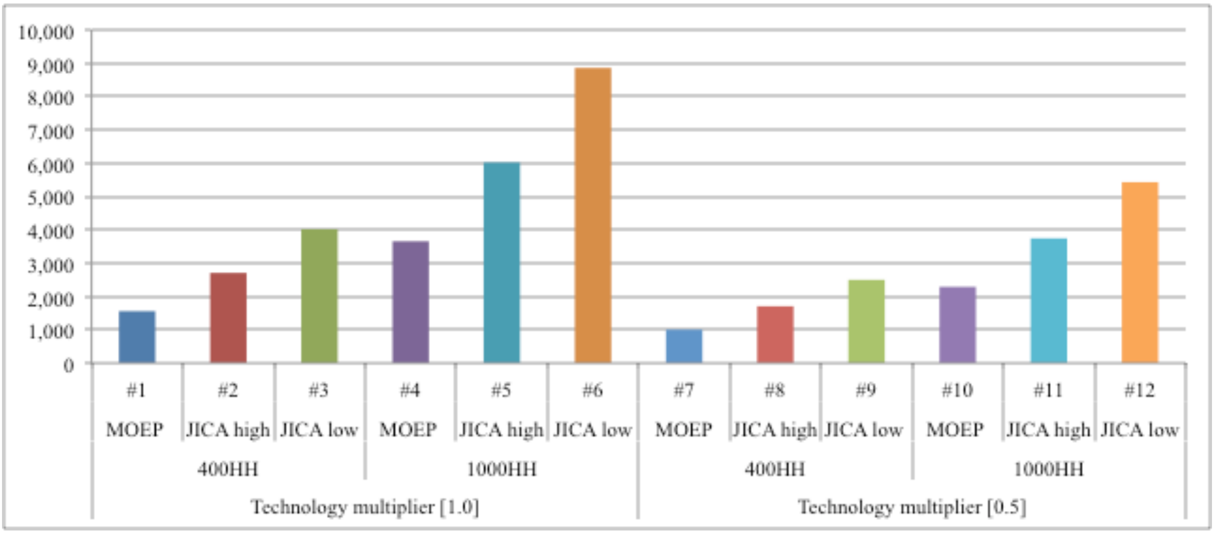

Figure 3 Cost comparisons for scenarios (Unit: MUSD)

DISCUSSION

In Myanmar, rural electrification is an important objective that must be achieved as soon as possible. Although the government has been working on extensive grid elongation, we regard off-grid electric power systems as holding an extremely important position in Myanmar's future. While plans for off-grid systems for rural electrification are being discussed, analyses based on economical relevance present an urgent issue.

Based on the result of demand forecast, we calculated the costs for rural electrification for 15 years from 2015–2030 using simulation software (HOMER) designed for the resolution of optimization problems for energy generation with variable output. We also obtained quantitative viewpoints. Specifically, we calculated the total net present cost per micro-grid unit. Particulars of the micro-grid we considered are the following: First, we considered two demand levels of 400 kWh and 1,000 kWh as the electric power demand per representative unit household. Furthermore, as the micro-grid size, the numbers of households per micro-grid unit of 100, 300, and 1,000 households are used and set as typical micro-grid sizes. Considering that the electrification potential depends on every micro-grid, we considered the following three micro-grid types. The first is a renewable energy type micro-grid using solar power generation, biomass power generation, and batteries. Second, we considered a hydropower generation type micro-grid relying on hydropower generation. Lastly, we considered a diesel power generation type micro-grid assuming that areas exist in which power generation should be covered to a certain extent by diesel power generation. We calculated the unit price per micro-grid for all combinations of demand per household, micro-grid size, and micro-grid composition. Based on the electric power demand forecast, seven states unable to attain 100 percent electrification by grid electrification even by 2030 were targeted. We considered that costs for necessary nationwide rural electrification are calculable by integrating the number of micro-grids for every state using this unit price.

Using a renewable energy type micro-grid, we calculated costs for every state based on solar power generation and biomass potential data. By state, Ayeyarwaddy state showed the lowest cost per unit micro-grid: from 70,100 USD (400 kWh, 100 households) to 2,191,650 USD (1,000 kWh, 100 households). This is attributable to the fact that Ayeyarwaddy state has the highest biomass potential, thereby supporting effective biomass power generation. Storage of the produced biomass is not considered in the present calculations. We assumed that the produced biomass is useful as fuel with no modification. Biomass power generation exceeding the current calculation results can be expected if storage is considered. This country has higher biomass potential, and biomass power generation is expected to be developed.

The costs associated with solar power generation and lithium ion batteries are expected to decrease markedly in the future. The benefits of price reduction by technological progress can be enjoyed greatly even by rural electrification in developing countries. Regarding sensitivity analysis, we then calculated the costs per micro-grid unit considering the reduction in costs of solar power generation and lithium ion batteries.

The following was considered based on the results of the calculations of the cost of each scenario.

The regional electrification plan in each scenario is greatly impacted by the scale of the electric power that will be supplied to the grid. In Scenario 6, which is the JICA low case (9,100 MW), the load placed on off-grid electrification is highest. Costs approximating USD 9 billion are required. Therefore, the percentage of grid electrification must be maximized. It is also necessary to either promote power development linked to the national grid further or to increase the percentage allocated to the regional power supply. However, in Scenarios 1, 4, 7 and 10, that are MOEP cases (19,217 MW), which supply the most power, the cost will range from USD 1–4 billion. Therefore, in fact, it might be necessary to consider lowering the target electrification rate for 2030.

The fall of prices resulting from technological progress in photovoltaic power production equipment (including batteries) that are part of a micro-grid applied to off-grid electrification is also a highly influential factor. Scenarios 7–12 can obtain cost reduction equal to nearly half of the scenarios applying current prices (Scenarios 1–6). For this reason, we think that a schedule that shifts electrification by a micro-grid including photovoltaic power production to a later year would be effective.

Diesel power sources should not be used widely for rural electrification considering the need to reduce the use of fossil fuels. However, because of their mobility and convenience, by which they can begin operating immediately, they are regarded as effective within a range allowed by the price of fuel. Building a micro-grid based on small hydropower and other renewable energies requires lead time for surveying, planning, and construction, so electrification by introducing diesel as a temporary measure, then moving the equipment to another unelectrified region after completion of the construction of a micro-grid can be considered.

By replacing micro-hydropower (1 kW – 1 MW), which features the lowest unit price of power, with small hydropower (1 MW – 10 MW), which provides larger output, the efficient supply of power to multiple villages is relied upon to lower power production costs by taking advantage of economies of scale.

CONCLUSION

This research reported results of a study of rural electrification. Based on those results, the challenges to promoting electrification were identified. Countermeasures to overcoming these challenges were considered.

The most efficient and economical method of carrying out rural electrification is grid extension, but an important prerequisite for this process is ensuring the capacity to supply power to the grid. Without such assurance, grid extension would be meaningless. Regarding grid supply capacity, rural grid electrification under the National Grid supply plans (MOEP case, JICA high case and JICA low case), which were planned based on the JICA master plan, survey were verified, but it has been predicted that insufficient capacity to supply the grid will restrict improvement of the electrification rate by grid extension.

Enormous budget will be required for power development and transmission expansion plans proposed by JICA. To electrify off-grid will be put lower the priority. In that sense, we estimate that the country will have difficulty to meet 100% electrification rate for 2030.

Accordingly, it might be necessary to establish a more practical plan as a low priority rural electrification plan (with the target electrification rate lowered from 100 percent to between 70 percent and 80 percent).

Because of inadequate capacity to supply a rural grid, in addition to grid extension, off-grid electrification must be actively promoted within the range allowed by budgets. To make efficient power supply to plural un-electrified villages, the promotion of medium and small hydropower development as one measure to boost capacity to supply the rural grid is expected to be required. It is also expected that medium and small hydropower (1 MW – 100 MW) will be positioned with power plants that will be the core of supply to regional cities (will not supply large cities). They will also contribute to the rural electrification of regional cities and surrounding villages (local production for local consumption as the key words). Micro-hydropower (less than 1 MW), however, can be provided at lower power generation cost than diesel, photovoltaic, or biomass, so this type must be constructed widely as power sources for off-grid electrification to promote rural electrification at the village level.

In response to the identification of the challenges presented above, a list of concrete measures to establish the environment for medium and small hydropower development and the promotion of off-grid electrification has been prepared.

Medium and small hydropower planning surveys, renewable-energy-based electrification planning surveys, preparation of basic documents (renewable energy potential survey, preparing meteorological, hydrologic, and topographical maps, etc.), and village surveys (population and demand survey, survey of living standards and tariffs users will be willing to pay, etc.)

- Selecting organizations to conduct development projects (ESE, IPP, local governments, etc.), procuring funds (REF, microfinance, etc.)
- Financial support system (FIT, etc.), preservation measures such as tax exemptions, revising electricity tariffs and fee tariff systems
- Personnel development (to enact and manage development projects, operator training, etc.)

This research is limited by the paucity of available data. Although various institutions including the World Bank have been collecting data, reliable data related to rural electrification are scarce. This research simply calculated the approximate costs based on numerous assumptions. We used the limited data available in this country and appropriate data from existing data available in neighboring countries. In Myanmar, the national population census was conducted in 2014; data are being compiled actively and continually. We believe that the presentation of cost calculation methods for the realization of rural electrification and for scenarios produced by the cost calculation to the government of this country will be extremely helpful for them in planning rural electrification.

NOMENCLATURE

MOI: Ministry of Industry
MLFRD: Ministry of Livestock, Fishery and Rural Development
MOEP: Ministry of Electric Power
ADB: Asia Development Bank
JICA: Japan International Cooperation Agency
WB: World Bank
NEMC: National Energy Management Committee
LRMC: Long-Run Marginal Cost
SHS: Solar Home System
NEP: National Electrification Plan
DRD: Department of Rural Development
HOMER: Hybrid Optimization Model for Electric Renewable
COE: Cost of electricity
NPC: Net present cost (NPC)
HH: Household
RE: Renewable energy
PV: Photovoltaic
MEPE: Myanmar Electric Power Enterprise
MIC: Myanmar Inventors Cooperative Ltd.
LHV: Lower Heating Value
ESE: Electric Supply Enterprise
IPP: Independent Power Producer
FIT: Feed in Tariff

ACKNOWLEDGEMENT

This research has been supported by Economic Research Institute for ASEAN and East Asia (ERIA).

REFERENCES

1. Asian Development Bank and the Myanmar Ministry of Energy. (2014). Updating Energy Sector Development Plan, Project number: TA No. 8356-MYA Draft Report for Discussion, Consolidated demand forecasts (Biomass, Liquid Fuels, Electricity)
2. CASTALIA. (2014). Myanmar National Electrification Program (NEP) Roadmap and Investment Prospectus Draft Final Road Map and Investment Prospectus.
3. Candelise, C., Winskel, M., & Gross, R. J. (2013). The dynamics of solar PV costs and prices as a challenge for technology forecasting. *Renewable and Sustainable Energy Reviews*, *26*, 96-107.
4. Earth Institute, Sustainable Engineering Lab Colombia University (2014). Myanmar National Electrification Plan (NEP): Least-Cost Geospatial Electrification Planning Results, DRAFT – Final Report.
5. Gerry, S. (2013). Optimal rural microgrid energy management using HOMER.*International Journal of Innovations in Engineering and Technology*, *2*(1), 113-118.
6. Jain, A. (2006). Design parameters for a rice husk throatless gasifier reactor.
7. Japan International Cooperation Agency (JICA). (2015). *The National Electricity Master Plan in Myanmar, Final Report.* Japan International Cooperation Agency (JICA).

8. Kanase-Patil, A. B., Saini, R. P., & Sharma, M. P. (2010). *Integrated renewable energy systems for off grid rural electrification of remote area*. Renewable Energy, 35(6), 1342-1349.
9. Nandi, S. K., & Ghosh, H. R. (2010). Prospect of wind–PV-battery hybrid power system as an alternative to grid extension in Bangladesh. *Energy*, *35*(7), 3040-3047.
10. Nykvist, B., & Nilsson, M. (2015). Rapidly falling costs of battery packs for electric vehicles. *Nature Climate Change*.
11. Shaahid, S. M., & El-Amin, I. (2009). Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia—a way forward for sustainable development. *Renewable and Sustainable Energy Reviews*, *13*(3), 625-633.
12. Yee, T. T. H., Win, S. S., & Soe, N. N. (2008). Solar energy potential and applications in Myanmar. In *Proceedings of World Academy of Science, Engineering and Technology* (Vol. 32).