Energy for Sustainable Development 27 (2015) 1–9

Contents lists available at ScienceDirect

Energy for Sustainable Development

Issues of small scale renewable energy systems installed in rural Soum centres in Mongolia

Khishigt Tamir, Tania Urmee *, Trevor Pryor

Murdoch University, Perth, Western Australia, Australia

ARTICLE INFO

Article history:
Received 8 January 2014
Revised 30 March 2015
Accepted 4 April 2015
Available online xxxx

Keywords:
Mongolia
Renewable energy systems
Soum centres
Demand management
Maintenance and monitoring

ABSTRACT

In Mongolia, 43% of the total population lives in remote areas where supplying sufficient electricity through the existing grid is difficult due to terrain. The Mongolian government intends to utilize renewable energy systems to supply electricity in these areas and, as a first stage, financed 12 renewable energy hybrid systems but these systems failed to operate as planned. These projects are evaluated in this study based on government documents and other research reports and it is found that most of these systems are unsuccessful in providing the required services. The lessons learned from the failed installations are documented in this paper. Local technician training and user education is also important as technology transfer is very important for remote area systems. The research reveals the fact that introducing new technology does not solve a problem. To reduce the chance of failure, proper sizing and quality equipment selection are very important in such a harsh climatic zone. The results of the analysis show that inadequate attention was given to sizing the system, which led to customer dissatisfaction and unwillingness to pay.

Introduction

Electricity plays a vital role in contributing social and economic benefits to rural communities which comprise 52% of the world population (Byrne et al., 2007). The World Summit on Sustainable Development explicitly identified having access to primary energy is essential for achieving the UN Millennium Development Goal of reducing poverty by 50% in the world's poorest countries by 2015 (Modi et al., 2006). According to a recent United Nations Development Programme (UNDP) report more than 1.3 billion people in rural areas of developing countries currently lack access to reliable electricity (World Energy Outlook, 2013).

Providing electrification in remote rural communities using renewable energy (RE) technologies is a practical option (Urmee and Harries, 2009). Small-scale diesel/gasoline generators have been used for decades to serve the rural electricity needs. In places where grid access is technically impossible and financially infeasible, renewable energy systems can play an important role in power supply. These technologies are especially suitable for remote places where it is difficult to supply diesel fuel and where people cannot afford to pay the high cost of electricity produced by fossil fuel technology (Surendra et al., 2011).

In Mongolian rural areas, especially for *Soum* (village or settled area) centres (SCs) which are located more than 1000 km from the capital city and over 500 km from the Aymag (province) centres, electricity supply is vital for providing the basic needs of the people in those areas. Supplying these areas with electricity from diesel generators is not feasible as it requires imported diesel fuel paid by foreign currency, which is sensitive to foreign exchange rates and high cost for transportation due to poor infrastructure, resulting in a high bill for the customers (ESCAP, 2007). The government of Mongolia intends to utilize renewable energy systems as an energy supply solution for rural SC in the future (ESCAP, 2007). In 2007 and 2008, the government of Mongolia financed 12 projects out of the State budget which were aimed at creating RE systems at remote SCs. However, most of the installed RE systems had both technical and non-technical problems which resulted in the shutting down of the operation of these systems after a few years of operation. Almost all of the renewable energy systems installed in the SCs have experienced technical faults and problems since their inception (EAM, 2010n). In order to learn lessons for future projects, this paper will investigate and identify the drivers and barriers that have been experienced by these 12 RE projects.

Background

Mongolia is a land-locked country located within 87° 44′E and 119° 56′E longitude and between 41° 35′–44′N and 52° 09′N latitude in the North of Central Asia (Maps of World. Mongolia Latitude, 2013). The total land area is 1,564,116 sq km with landscapes that include vast semi-desert and desert plains as well as grassy plains. It has an extremely large land mass with a majority of the population living in rural areas. Mongolia has five ecological zones namely, Forest Steppe, High mountain, Steppe, desert steppe and Desert (Jamsranjav, 2009). Mongolia has a democratic political structure. There are 21 Aymags (provinces), and 1

* Corresponding author. Tel.: +61 8 93601316; fax: +61 8 9360 6332.
E-mail address: t.urmee@murdoch.edu.au (T. Urmee).

http://dx.doi.org/10.1016/j.esd.2015.04.002
0973-0826/

metropolis (Ulaanbaatar) (see Fig. 1); within the 21 Aymags there are 331 *Soum*s, which are the lowest units of provincial administration.

The *Soum*s are composed of 1453 baghs which are the lowest level in the Mongolian administration in rural areas. This research studied the systems installed in Altai, Bayankhongor, Umnugovi, Dornogovi, Hovd and Dornod Aymag. These Aymags are situated in very diverse geographic areas e.g. the mountainous and wooded Khangai, steppe region, and the Gobi desert region. The selected SCs under this study are mostly in the steppe and Gobi regions.

Ulaanbaatar city, the coldest capital city in the world has 9 districts which are subdivided into 117 khoroos, which are the lowest units of city administration. These local administrative units (baghs and khoroos) are the base of a political hierarchy which is topped by the national government (USAID, 2010). Mongolia's climate is harsh continental (ADB (Asian Development Bank), 2011). The average altitude of the Mongolian plateau is about 1580 m above sea level.

According to a survey carried out by the National Statistical Office of Mongolia in 2010, the average annual household income ranges from MNT 1,296,000–2,400,000 (US$673.2–US$1308.5)[1] depending on geographical location and the size of the *Soum* (for instance some *Soum*s close to Aymag centres or big cities, or railways or paved road, or borders, or having access to the centralized electricity grid, have more income opportunities (NSO, 2011)). About 33% of the population live without electricity; and 43% is without access to central heating. This lack of access to electricity is especially acute outside of urban areas, where there is limited energy infrastructure (USAID, 2006).

Government energy policy and strategy

The Mongolian Government restructured the energy sector, through the enactment of a new energy law approved by the Parliament of Mongolia in 2001. The former Energy Authority was a vertically integrated monopoly which was “unbundled” so that 18 new state-owned energy companies could be established. Energy activities were divided into different fields such as generation, transmission, distribution, supply, and dispatching. The implemented Energy Law provides a basic regulatory, inspection, and enforcement structure for generators, transmitters, distributors, suppliers, and consumers. The Energy Law allows private and public sector involvement in the production of energy and establishes key policies in the areas of tariffs, energy efficiency, environmental quality, and safety (ADB, 2007).

The government has also focused on improving rural living conditions to reduce the migration of the rural population to the cities, in particular, to the capital Ulaanbaatar. This migration creates additional demands on schools, hospitals, and other social infrastructure services that cannot be met in the short to medium term. Government funds are no longer adequate to fully meet public infrastructure needs for health, education, and energy supply. The disparity between the reality and expectations based on past service levels in rural areas (which were based on heavily subsidized services provided by a centralized government) is contributing to the accelerated migration toward city centres, particularly to Ulaanbaatar. Poor electricity supply is a key contributor to the deterioration of these public services in rural areas. The Government of Mongolia has taken the initiative to increase the RE share of electricity generation (James et al., 2002). Current RE share is 3.3% (REN21, 2014) and the government set an ambitious goal to generate 15–20 % of the total electricity through renewable energy by 2020. In the last 10 years, the Government of Mongolia has invested heavily in constructing many mini hydro power plants and hybrid renewable energy plants in rural areas. The government is promoting the development of renewable energy, both in large-scale utility and small-scale remote area power supply applications (ADB, 2007).

[1] US$1 = 1700 MNT.

Profile of Mongolia's energy sector

Mongolia has three interconnected electricity grids, two isolated grids as well as electricity imports from Russia. The energy sector consists of four independent electric power systems (Srinivasan, 2005):

- Central Energy System (CES)
- Eastern Energy System (EES)
- Western Energy System (WES)
- Altai Uliastai Energy System

There are essentially three separate markets for electricity in Mongolia. The first and largest market includes all grid-connected cities and towns and is dominated by Ulaanbaatar, the capital city. Total capacity of the CES as of 2011 is 786.3 MW. This market accounts for some 87% of the total electricity supply, and reliability averages 23 h/day (IEEJ, 2012). The second market, the EES, consists of mainly off-grid *Soum* centres, where stand-alone diesel generators, with a total capacity of only 36 MW, provide limited services. This market accounts for about 3% of the total electricity supply. The EES supplies electricity to two provincial capitals (Sukhbaatar and Dornod); there are about 18 *Soum* centres in these provinces. The EES also supplies heat to the provincial capital of Dornod province (James et al., 2002).

The WES and CES have a constant supply from Russia. Around 10 MW is imported from Russia into the WES and up to 130 MW into CES during peak demand. Maximum available capacity from Russia is 250 MW (IEEJ, 2012). The WES market services the nomadic herders; is highly decentralized, and remains largely undeveloped. Household-based power supply systems are the only option for this market. Numerous off-grid rural *Soum* centres have a local diesel power supply (REEEP, 2012a). Due to increased demand for electricity, Mongolia is in danger of a serious shortfall of energy by early 2020 (IEEJ, 2012). Power imported from Russia may not be able to meet the increased demand and, even if it did, it would be very expensive; therefore, renewable energy systems have extremely good potential to supply power in remote rural areas.

Renewable energy applications in Mongolia

Mongolia has good solar energy resources, typically receiving annual average solar irradiation values of between 4.55 and 6 kWh/m^2 per day (ESCAP, 2007). It has significant wind energy resources (IRENA, 2012). In almost every part of the steppe region, the average annual wind speed is no less than 5 m/s, while mean wind speeds of 5–6.5 m/s are available in the Gobi region (ESCAP, 2007). Wind energy is a practical and economical solution for the nomadic families and at bagh-centres, which are the service units closest to the nomadic livestock herders (Surendra et al., 2011; ESCAP, 2007; Batsuk, 1996). In 2002, 40,000 herders received solar home systems (SHS) through a national programme supported by the Chinese government and the Japan International Cooperation Agency (JICA) (REEEP, 2012b). Some village power systems comprising wind/PV hybrid systems and Solar Photovoltaic (PV) village power systems were also built. These were financed by the New Energy Industrial Technology Development Organization (NEDO) of Japan (REEEP, 2012b).

A large number of the renewable energy projects implemented were demonstration projects, financed by foreign donor organizations. Equipment used in these projects was mostly imported. Experts, scientists and technicians of the Mongolian Academy of Sciences, and the Universities, undertook these projects. At present, more than 105,000 solar home systems (SHSs) reportedly are in use by herders for lighting, operating radio receivers, TV sets, satellite dishes or charging mobile phones. The PV systems have capacities in the range of 5 to 200 Wp. In addition, over 4500 wind generators are reportedly in use in rural areas, with capacities mainly between 50 and 200 W (NREC, 2007).

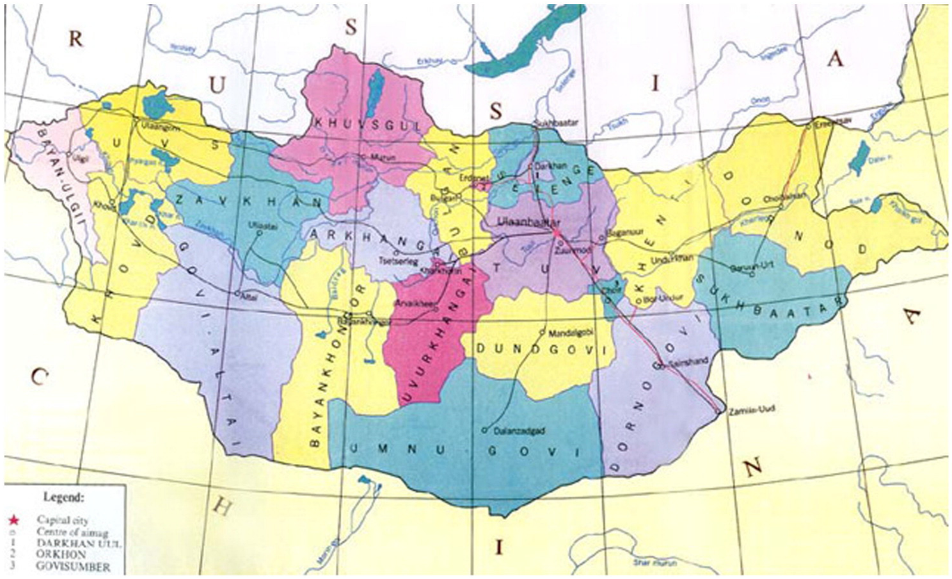

Fig. 1. Administrative map of Mongolia (showing the 21 Aymags and their main provincial centres) (Maps.com., 2011).

In this study, the sizes of the turbines ranges between 7.5 kW and 20 kW.

Under the National Programme for Renewable Energy of Mongolia, the Government of Mongolia electrified 12 *Soum* centres remotely located from the centralized grids. According to National Renewable Energy Center (NREC) (NREC, 2007), these areas have good wind power resources. These centres are electrified by solar, wind-diesel or wind-solar-diesel or solar–wind hybrid power systems, and form the main focus of this study.

Methodology

Fig. 2 shows the research methodology used for this study.

A literature review was undertaken to identify appropriate criteria for the evaluation of renewable energy projects. According to the literature, most of the issues affecting the success of such projects are (Martinot, 1999, 2002; Urmee et al., 2009; Cabraal and Martinot, 2000; Martinot et al., 2001; Nieuwenhout et al., 2000):

i. Resource assessment
ii. Equipment selection process and quality control
iii. Installation, operation and maintenance
iv. Selection of stakeholder (ownership)
v. Technology transfer and development of local expertise
vi. Financial

In this research, information obtained from the Energy Authority of Mongolia (EAM) was investigated in detail and summarized under the above broad categories. The EAM information included photographs, field reports, electricity generation data, and some technical drawings. Reports prepared by experts from the EAM included all related information such as design, installation processes, commissioning, operation, maintenance, the conclusion of turnkey contracts, and the technical and non-technical problems which occurred in these systems. EAM staff carried out detailed site inspections at the 12 *Soum* centres. Based on this analysis, the drivers and barriers that have been experienced during pre- and post-implementation of these RE projects were identified and summarized as lessons learned.

Status of small scale RESs installed in centres of rural *Soums* in Mongolia

At *Soum* centres, electricity is used for the lighting of households and organizations. Almost all lights are incandescent bulbs. Households usually have a radio receiver (operated by battery) a TV set, video CD and DVD players, electric kettles and an iron. Nowadays, some families have a refrigerator, a washing machine and a microwave. Organizations' main use of electricity is also for lighting. Some organizations have desktop computers and other electronic devices, such as music systems, video projectors, photocopying machines, fax machines, fans and printers. School dormitories usually have a large washing machine, irons and TV. Hospitals have a refrigerator and an electric kettle (Adiyabat and Kurokawa, 2004).

Out of twelve projects investigated by the Energy Authority of Mongolia (EAM), four systems are wind–PV–battery hybrid systems, two are wind–PV–diesel hybrids, two are PV-battery only and the rest (4) are wind–battery hybrid systems (Bergmann et al., 2011). The number of households connected in each system ranges from 110 to 370. The loads and technical details of the systems are summarized in Table 1 below.

At the time of the assessments (2009), 33% (4) (wind–battery) systems had been shut down completely, 16% (2) (solar PV only) systems were working and the remaining 50% of the systems (6 solar–wind hybrid) often experienced technical problems related to the wind turbine, battery bank, and/or the control system. As we can see from the above table that the problems found in these systems are not related with diesel generator.

Assessment of the RESs installed in rural *Soums*

The following observations are drawn from government reports, literature and different donor reports (EAM, 2010n; ADB (Asian Development Bank), 2011; Adiyabat and Kurokawa, 2004; ABB, 2003; ACE, 2003; ADB, 2005; EAM, 2010c; EAM, 2010d; EAM, 2010e; EAM, 2010f; EAM, 2010g; EAM, 2010h; EAM, 2010a; EAM, 2010i; EAM, 2010j; EAM, 2010k; EAM, 2010l; EAM, 2010m; EAM, 2010b; Ministry of Power Energy and Resources, 2006; UNCTAD, 2010).

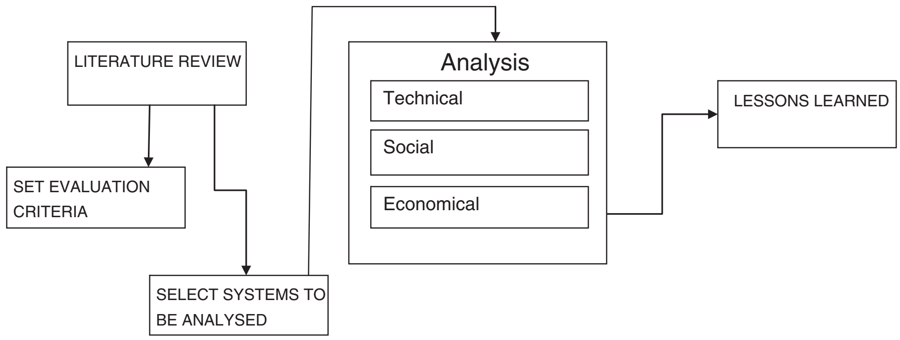

Fig. 2. Flow chart of research methodology.

Resource assessment

Only one Soum centre (namely Mandakh Soum in Dornogovi Aimag) out of the twelve centres has a wind measurement device installed, with measurement being made for a period of three years. The assessment of the wind energy resource was made appropriately in this case, and the expected electricity generation was calculated based on the resource data and the power curve of the wind turbine in advance. This system met users' demand and working well until the battery and control system failed within one year of installation (Batbayar C., Senior officer, Renewable Energy Division, Ministry of Energy of Mongolia, Personal communications, July, 2009). However, for the other renewable energy systems, measuring devices such as pyranometers, anemometers, wind direction vanes, ambient temperature sensors, or atmospheric pressure recorders were not installed to measure the actual solar and wind energy resources. A general solar radiation map of Mongolia was used to determine

Table 1
Components and loads of selected RE systems installed in Mongolia.

System's name	Capacity of the system (kW)	Components of the renewable energy systems	Load		
			No. of connections (households (HH) and shops	Summer load (kWh/day)	Winter load (kWh/day)
Tseel *Soum* of Gobi-Altai Aymag, solar–wind hybrid system	150	Wind turbines: (6 × 20 kW), solar system: (230 × 0.13 kW), inverter: 1 × 132 kVA (capacity), DC500/AC380 V, battery: (800 Ah (2 V) × 500 units).	120 HH, 8 buildings and small shops	852	910
Manlai *Soum* of Umnugovi Aymag, solar–wind hybrid power system	150	Wind turbines: (12 × 10 kW), solar system: 30 kW; inverter: (1 × 75 kVA (and (1 × 150 kVA), battery: (1000 Ah (2 V) × 360 units)	200 HH and a few buildings and shops	566	897
Shinejinst *Soum* Bayankhongor Aymag, solar–wind hybrid system	150	Wind turbines: 90 kW (12 × 7.5 kW, solar system: (180 × 0.18 kW), inverter: (2 units × 60 kVA), battery: (1000 Ah (2 V) × 360 units), control box: SCP-240120 type.	120 HH, few buildings and small shops	491	607
Bayan-Undur *Soum*, Bayankhongor Aymag, 150 kW solar–wind–diesel hybrid system	150	Wind turbines: (12 × 7.5 kW), solar system: 30 kW, inverter: (2 units × 60 kVA, battery: (1000 Ah (2V) × 360 pieces), diesel: 100 kW	120 HH, few buildings and small shops	730	820
Bayantsagaan *Soum* of Bayankhongor Aymag, solar–wind–diesel hybrid systems	150	Wind turbines: (12 × 10 kW), solar system: 30 kW, inverter: (2 units × 60 kVA), battery: (1000 Ah (2 V) × 360 units), diesel: 100 kW	340 HH, 20 buildings and small shops	625	703
Matad *Soum* of Dornod Aymag, solar–wind hybrid system	120	Wind turbines: (9 × 10 kW), solar system: 30 kW, inverter: (2 units × 60 kVA (40 kVA).	150 HH, few buildings and small shops	599	700
Bugat *Soum* of Gobi-Altai Aymag, 140 kW solar system	140	Solar system: 140 kW, inverter: (1 × 60) kVA & (1 × 100) kVA, battery: (1000 Ah (2 V) × 600, charge controller—4 units	130 HH, few buildings and small shops	584	725
Tsetseg *Soum* of Hovd Aymag, solar system	100	Solar system: 100 kW, inverter: (2 × 60 kVA each, battery: (1000 Ah (2 V) × 360 units), charge controller—(SCP-240120)	120 HH, few buildings and small shops	533	713
Khatanbulag *Soum* of Dornogovi Aymag, wind battery system	150	Wind turbines: (15 × 10 kW), inverter: (2 × 150 kVA (480 V), battery: 1000 Ah (2 V) × 240 units	140 HH, 10 buildings and small shops	590	780
Mandakh *Soum* of Dornogovi Aymag, wind-battery system	80	Wind turbines: (8 × 10 kW), inverter: 100 kVA, CPTT-180 kVA, battery: 1000 Ah (2 V) × 360 units, rectifier: 3 × 380, 60 kW, GDF-60 kW	110 HH and 10 shops	503	772
Sevrei *Soum* of Umnugovi Aymag, wind battery system	80	Wind turbines: (4 × 20 kW), inverter: 100 kVA, battery: 1200 Ah (2 V) × 250 units	110 HH, 10 buildings and shops	644	699
Bogd *Soum* of Uvurkhangai Aymag, wind battery system	80	Wind turbines: (4 × 20 kW), inverter: 100 kVA, battery: 1200 Ah (2 V) × 250 units	370 HH, 20 buildings and small shops	854	900

available solar radiation at project sites. In fact, for nine cases, the wind turbines were installed at places where no wind energy resource data were available.

Although there is no direct evidence that lack of an assessment adversely impacted on the performance of these system but according to the literature, resource assessment for renewable energy sources is very important (Zhoua et al., 2010; Whale et al., 2013). Whale et al. (2013) show that performance of wind turbines is very site-specific, especially in mountainous areas where the wind regimen actually depends on the topography of that specific area (Whale et al., 2013). According to the EAM (2010a, 2010b, 2010c, 2010d, 2010e, 2010f, 2010g, 2010h, 2010i, 2010j, 2010k, 2010l, 2010m, 2010n), due to a sudden decision made by the Parliament and Government, there was not enough time to implement a resource-measuring campaign; thus, solar and wind energy resources were not assessed in detail through measurement by installed measuring devices (EAM, 2010n).

Equipment selection and quality control

In most cases, the equipment was selected by the contractors, who had little or no experience in installation, or in the operation of renewable energy devices. Almost all equipment and devices were imported from China, which is the closest supplier. However, when selecting equipment such as wind turbines, some of the contractors did not consider whether the selected equipment would work in the extremely harsh conditions of Mongolia nor did they take into account the extreme isolation and difficult installation conditions (EAM, 2010b, 2010n). Because of budget constraints, the contractors had to buy low quality devices, which increased maintenance costs and decreased the reliability of the system (ESCAP, 2007).

Installation

In almost all installations involving wind turbines, the turbines had broken down during their operation due to mal-functioning controllers, or damage incurred during periods of strong winds. The problems documented during the investigation by EAM regarding installation are highlighted in Table 2. In the case of wind turbines, the main problem was damage by strong wind.

As mentioned in Table 2, some of the technical problems occurred due to incorrect installation. A common problem related to solar PV panels was that the distance between two arrays was too short and arrays were installed too close together. As a result, the array in front partly shadows the array standing behind (as shown in Fig. 7) and reduces the output power. In five systems, this issue had been addressed by removing either the front or rear arrays or re-installing to a different position where they will not be shadowed by any object.

Operation, maintenance and management

According to the field reports conducted by EAM (2010a, 2010b, 2010c, 2010d, 2010e, 2010f, 2010g, 2010h, 2010i, 2010j, 2010k, 2010l, 2010m, 2010n), wind turbines require more maintenance and regular inspection for their safe and reliable operation (EAM, 2010n). Although solar PV panels typically require little care during their operation, in the Mongolian case during winter, the snow on the panels needs to be cleared after each snowfall, as the panels will not generate electricity if there is snow on them. It has been observed that snow accumulation does affect PV performance and the extent to which snow impacts on PV performance is difficult to determine because snow events also increase the uncertainty of the solar radiation measurement (Marion et al., 2009; Powers et al., 2010). Therefore a regular cleaning is needed to increase the system performance.

In Soum centres, there are a few officers who administer the centre and are responsible for civil service and other administrative issues. However, according to the administrative policy, the Soum administration is also responsible for management of renewable energy systems and revenue collection at the Soum centre (EAM, 2010b). System operators are usually tractor drivers who previously worked as diesel operators, with limited knowledge of electrical theory and devices. Because of the low level of the fixed tariff, some Soums have only one person in charge for operation, maintenance, and sales revenue collection tasks. These operators are familiar with diesel generator operation and after the failure of renewable energy system diesel generators continue to supply power. There are no organizations available to provide after-

Table 2
Common technical problems, occurring at renewable energy hybrid systems in 12 *Soum* centres in Mongolia.

No	Names of RE hybrid systems	Types of common malfunction and technical problems									
		Wind turbine not working	Unusual damage	Control Circuit Csystems (Controllers)	Battery failure	Charge and load regulator	Inverter	Control and power cables	Incorrect installation	Other damage	Lack of measuring devices
1	Tseel Soum's 150 kW S–W hybrid system	✓		✓					✓		✓
2	Manlai Soum's 150 kW S–W hybrid system	✓		✓	✓	✓	✓	✓	✓	✓	
3	Shinejinst Soum's 150 kW S–W hybrid system	✓		✓	✓				✓		
4	Bayan-Undur Soum's 150 kW S–W hybrid systems	✓		✓		✓			✓		
5	Bayantsagaan Soum's 150 kW S–W hybrid system	✓		✓	✓	✓			✓		✓
6	Matad Soum's 120 kW solar-wind hybrid systems	✓		✓					✓		
7	Bugat Soum's 140 kW solar system								✓		
8	Tsetseg Soum's 100 kW solar system		✓	✓			✓		✓	✓	
9	Khatanbulag Soum's 150 kW wind system	✓		✓		✓					
10	Mandakh Soum's 80 kW wind system			✓	✓						
11	Sevrei Soum's 80 kW wind system			✓	✓		✓			✓	✓
12	Bogd Soum's 80 kW wind system	✓		✓	✓					✓	

Fig. 3. A view of broken wind turbine (Turbine #2 Bogd *soum*).

sales service or maintenance for distribution lines (0.4 kV) at Soum centres. Therefore, the operation, maintenance, and revenue collection are generally conducted inefficiently. In any development work in Mongolia, corruption remains a serious issue (Foundation, 2013). Some governors were known to have dismissed pre-trained and prepared operators, then appointed untrained people as operators (EAM, 2010b, 2010j, 2010k, 2010l) who do not have any knowledge on the RE systems and thus caused system failure.

Technical review

Table 2 summarizes the technical problems found in according to the common malfunction and technical issue (EAM, 2010a, 2010b, 2010c, 2010d, 2010e, 2010f, 2010g, 2010i, 2010j, 2010k, 2010l, 2010m, 2010n).

Most of the problems were due to control circuit, incorrect installation, equipment failure, and battery failure (see Table 2). Further investigation uncovered the following issues:

- Some wind turbines fell down during strong winds (rotor, generator, together with supporting pole and guys were released) (see Fig. 3) (Bayan-Undur, Bayantsagaan, Matad, Khatanbulag and Bogd *soums*).
- Incorrect operation of the high wind cut-off mechanism of the wind turbines.
- The tower-fixing metal wires were loose and not fixed correctly and in some cases the foundation for fixing wires had structural damage which was one of the causes for the wind turbines collapsing (see Fig. 4).
- Damage to the electronic boards of the wind turbine controllers (EAM, 2010f, 2010g).
- In four systems, data collection software was in the Chinese language, and the previous logs could not be observed and were not recorded; the Control computer was out of order, and it is unclear what kind of software was used (EAM, 2010a, 2010c, 2010d, 2010e).
- No control system was installed (EAM, 2010k). The control system was non-functional and software was damaged (EAM, 2010i).
- A dump load was not installed.
- Batteries were out of order (Shinejinst *soum*—200 units, Bayantsagaan *soum*—21 units, Bugat *soum*—2 units, Bogd *soum*—37 units (EAM, 2010c; EAM, 2010e; EAM, 2010k; EAM, 2010m)).
- Batteries were installed in inappropriate environments or conditions, the result of which was that sulphate had formed in some batteries, and the odour in the battery room made the place unhygienic (EAM, 2010g) (see Fig. 5).
- In some cases, the battery connection was incorrect and did not provide the required voltage to the system (EAM, 2010f).
- In two centres the battery charge controller was not working, which significantly affected the battery life (EAM, 2010d, 2010e).

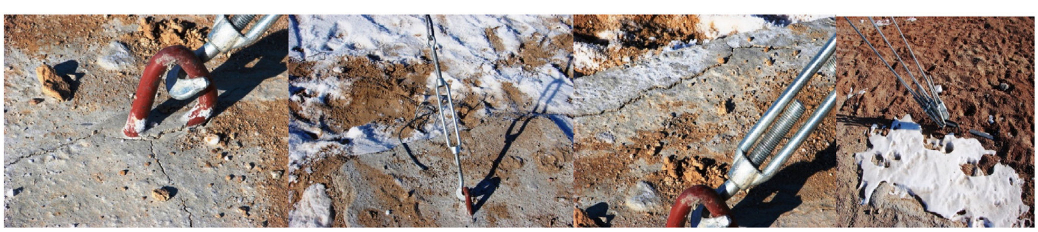

Fig. 4. Structural damage on wire-fixing foundation (Khatanbulag *soum*).

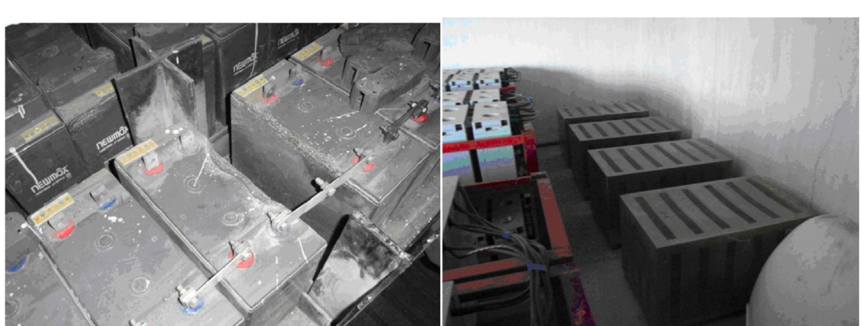

Fig. 5. Damaged batteries (Bugat *soum*).

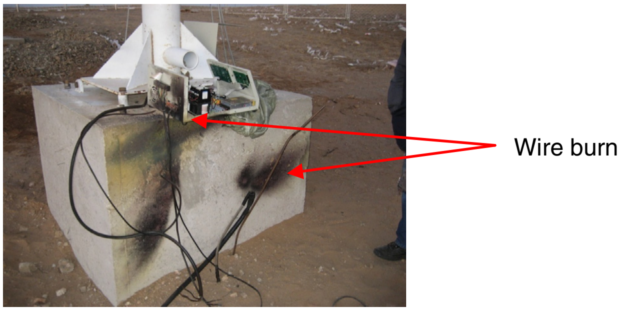

Fig. 6. Electrical cables could not withstand the load, incorrect connection, and supplied charge regulator did not meet requirements.

- In some cases, the inverter was out of order while in others a low capacity inverter was installed (EAM, 2010a, 2010c, 2010d, 2010e, 2010l, 2010m).
- Control signal cables from the wind turbines were damaged (Fig. 6).
- The connections of solar system components were incorrectly done and needed to be changed. The Contractor was requested to rectify those defects, (Manlai *soum*).
- There was insufficient distance (6 m) between the rows of solar panels, so that one row was shadowing another (see Fig. 7) (EAM, 2010f, 2010j, 2010k).

Unusual damage

In one case, (in the Umnugovi Province which is in the Gobi-Desert region), there was an animal which lives underground called a Zag's Rat which, to cope with a food deficiency, ate control cables (cables between the sensors and data acquisition system), and even power cables, and caused a short circuit in 2008. Although the contractor restored the system by replacing all damaged cables, another instance of similar damage occurred due to Zag's Rats eating the cables in November 2009 (EAM, 2010f). In another *Soum*, the glass of one PV module was damaged due to children playing or to deliberate vandalism (EAM, 2010c).

Technology transfer and users training

Technology transfer has not occurred successfully in this project. Operators do not have enough knowledge and skills on how to operate and maintain the installed RE systems. No general awareness training was provided to the users, so the people living at the *Soum* centres do not have a good understanding on the operational features of renewable energy systems nor knowledge about how to adjust their electricity consumption when renewable energy resources (solar and wind) are not available for some period. Overloading of the renewable energy system is a common phenomenon at Soum centres. This may be solved by increasing the power capacity or through demand reduction or both. The problem in this situation is, a lack of appropriate matching of capacity to demand. No user training was provided on the use of electricity at Soum centre to develop awareness among the users during low energy production by the system.

Accountability on system use and stakeholders participation

Although *Soum* administrations (local Government) are in charge of managing the renewable energy systems, the actual physical assets are considered as State Property. Thus, local governments at *Soum* centres have no responsibility for maintaining or taking care of the installed system. A report needs to be submitted to the State Property Committee on maintenance or replacement issues and the authority takes the final decision on maintenance problems (EAM, 2010b). As a result, *Soum* administrations have no obligation on the system use and so as the users. As a beneficiary of the system, one has to have responsibility for it, which is missing in these projects. In all reports regarding the installation of these renewable energy systems, the accountability on use of the system was mentioned as a major problem of system maintenance.

Another issue was raised by the community regarding stakeholders' participation. According to the community members, the local community was not invited to participate in the project implementation process. This also caused problems as the community was not happy with the outcome of the project (EAM, 2010b).

Financial

People living in the *Soum* centres pay a fixed amount or nothing (in some centres) for electricity usage due to the lack of installation of meters in each household. Thus, consumers do not have any financial motivation to reduce their electricity consumption. The information obtained from Energy Authority relating to tariffs and the success in their collection is shown in Table 3 below.

From Table 3 we can see that in most of the cases a tariff was not set. In some locations where a tariff was set, it was difficult to find the basis of the tariff setting. Different Aymags have different tariffs which indicates that tariff may be calculated as an ad-hoc process. In some centres the plant accrued money which was intended to be used for maintenance of the plant.

Conclusions and lessons learned

Mongolia has good potential renewable energy resources. However, the challenges of implementing renewable energy projects need to be addressed in order to meet the renewable energy target. Renewable energy systems studied in this research were installed at rural *Soum* centres in Mongolia in 2007–2008 and experienced a number of technical and non-technical problems. Among them were incorrect system sizing, resource and load assessment, and incorrect system installation.

Fig. 7. View of the incorrectly installed solar PV arrays (Tsetseg *soum*, 2009).

Table 3
Electricity tariff status of renewable energy systems (EAM, 2010b).

No	Name and location of installed RE systems	Tariffs for electricity supplied by the renewable energy hybrid systems
1	Tseel Soum of Gobi-Altai Aymag, 150 kW solar–wind hybrid system	Each household pays 8000.0 MNT per month. The bills collected could not fully cover operation and maintenance cost, and was totally spent on diesel fuel purchasing and workers' salaries.
2	Manlai Soum Umnugovi Aymag, 150 kW solar–wind hybrid system	People were not charged for electricity use. No tariff was set.
3	Shinejinst Soum Bayankhongor Aymag, 150 kW solar–wind hybrid power system	Since the plant was put into operation about 8.0 million MNT was collected as sales revenue by May 2009 and accrued 1.5 million MNT. Each household pays 10,000 MNT (US$6) per month.
4	Bayan-Undur Soum, Bayankhongor Aymag, 150 kW solar–wind hybrid systems	Since the plant was put into operation its sales revenue acquired and expenses spent are equal. Each household pays 3000.0 MNT per month.
5	Bayantsagaan Soum of Bayankhongor Aymag, 150 kW solar–wind hybrid system	No tariff was set. Community can use the electricity free of cost. In the report it was mentioned the necessity to set the tariff.
6	Matad Soum of Dornod Aymag, 120 kW solar–wind hybrid system	The Regulatory Board of Dornod Aymag has not set a tariff for this system yet. In the report it was mentioned the necessity to set the tariff.
7	Bugat Soum of Gobi-Altai Aymag, 140 kW solar system	No tariff was set. In the report it was mentioned the necessity to set the tariff.
8	Tsetseg Soum of Hovd Aymag, 100 kW solar system	Per household pays 5000 MNT per month Apartment household pays 6000 MNT per month Retired people pay 3000 MNT per month By April 2009 the plant had accrued 2.5 million MNT.
9	Khatanbulag Soum of Dornogovi Aymag, 150 kW wind system	Tariff was not set and approved by the beginning of 2010. In the report it was mentioned the necessity to set tariff.
10	Mandakh Soum of Dornogovi Aymag, 80 kW wind system	No tariff was set by Dornogovi Aymag's Regulatory Board by February 2010. In the report it was mentioned the necessity to set tariff.
11	Sevrei Soum of Umnugovi Aymag, 80 kW wind system	No information available. The Plant was shut down after the Soum centre connected to the grid.
12	Bogd Soum of Uvurkhangai Aymag, 80 kW wind system	No tariff was set by February 2010 (used old tariff—120 MNT/kWh) for new wind plant.

Mongolia's extreme weather conditions make it difficult to implement renewable energy technologies.

Other factors that influence the success of such RE projects are lack of maintenance and monitoring, and users and local technician training. The introduction of new technology does not solve a problem unless the technology is well explained to the users. This study shows that the expectation of the users was more than these RE systems could deliver. Therefore, users' education and training are very important. A local users' representative in the operational committee helps to develop sense of ownership among the users.

Another important issue is stakeholder involvement at the planning stage. This could solve the demand and supply mismatch problem. The correct operation and management of the system are also important. The successful operation of a power supply system is based on sound management that encourages productivity and quality improvement efforts and can only be sustained with a strong sense of responsibility, proper system design and quality control. A proper operation and management committee was not established to look after these systems.

From the study it was found that systems failed because low quality equipment was selected due to inadequate budgets and perhaps mismanagement of budgets. Also, equipment was selected by uninformed contractors who had no stake in the long-term performance of the systems. Also the design and installation problems led to poor performance and eventually complete failure of these projects. Contractors had not been adequately supervised by people who had a stake in the success of the projects.

The following specific lessons were learned in the process of analysing the RE systems installed in Mongolia:

- Selection of equipment is very important in such a harsh climatic zone. Sourcing the equipment from reliable supplies and providing for after sales service is an important parameter to consider while selecting the supplier.
- Sizing of the system is very important to give customer satisfaction. Sizing should be based on load demand and available resources.
- Close supervision from experts is needed during the installation. This will reduce the possibility of problems like wrong installation, incorrect wiring, etc.
- In the case of a hybrid system, there is a critical need to match the resources to harmonize with each other to operate as a whole system, which did not happen for the systems under review.
- *Soum*s could not operate and maintain the hybrid system, especially the control computer system due to lack of customer and technician training and technology transfer. Technology transfer is very important for these remote systems. A training manual including DO's and DON'Ts needs to be developed and kept in the centre to provide readily available quick maintenance services.

References

ABB. Access to electricity: a white paper on ABB's initiatives for access to electricity. Zurich, Switzerland: ABB; 2003.

ACE. Annual report. Asean Center for Energy; 2003.

ADB. Manila, 2006. Economic Outlook. 2006. http://www.adb.org/Documents/Books/ADO/2005/default.asp, 2005. [[cited 2007 25 September]; Available from].

ADB. Renewable energy for small towns and rural areas. Asian Development Bank; 2007.

ADB (Asian Development Bank). Ulaanbaatar low carbon energy supply project using public–private partnership model. Asian Development Bank; 2011.

Adiyabat Amarbayar, Kurokawa Kosuke. Photovoltaic systems for village electrification in Mongolia technoeconomic analysis of hybrid systems in rural community centers. Bangkok, Thailand: The international PCSEC-14. 2004; 2004.

Batsuk Bolormaa. Renewable energy sources in Mongolia. *Sustainable energy news* 1996. INFORSE; 1996.

Bergmann Jon, Overmyer Jerry, Wilie Brett. The flipped class: what it is and what it is not. 2011. http://www.thedailyriff.com/articles/the-flipped-class-conversation-689.php, 2011. [[cited 2012 January]; Available from].

Byrne John, Zhou Aiming, Shen Bo, Hughes Kristen. Evaluating the potential of small-scale renewable energy options to meet rural livelihoods needs: a GIS- and lifecycle cost-based assessment of Western China's options. Energy Policy 2007;35(8):4391–401. [2007].

Cabraal A, Martinot E. World bank solar home system projects: experiences and lessons learned 1993–2000. *World Renewable Energy Congress VI*. 2000. Brighton, UK. Oxford, UK: Elsevier Science; 2000.

EAM. Detailed introduction about Matad soum's centre in Dornod Aimag and renewable energy system. Energy Authority of Mongolia; 2010a.

EAM. Introduction about operation and maintenance status of renewable energy systems installed at centres of 12 remotely located soums in rural areas. Ulaanbaatar: Mongolia Energy Authority of Mongolia; 2010b.

EAM. Detailed introduction about Shinejinst soum's centre in Bayankhongor Aimag and renewable energy system installed Energy Authority of Mongolia; 2010 ac.

EAM. Detailed introduction about Bayan-Undur soum's centre in Bayankhongor Aimag and renewable energy system Energy Authority of Mongolia; 2010d.

EAM. Detailed introduction about Bayantsagaan soum's centre in Bayankhongor Aimag and renewable energy system Energy Authority of Mongolia; 2010e.

EAM. Detailed introduction about Manlai soum's centre in Umnugovi Aimag and renewable energy system Energy Authority of Mongolia; 2010f.

EAM. Detailed introduction about Khatanbulag soum's centre in Dornogovi Aimag and renewable energy system Energy Authority of Mongolia. 2010.

EAM. Detailed introduction about Mandakh soum's centre in Dornogovi Aimag and renewable energy system Energy Authority of Mongolia; 2010h.

EAM. Detailed introduction about Tseel soum's centre in Govi-Altai Aimag and renewable energy system Energy Authority of Mongolia; 2010i.

EAM. Detailed introduction about Tsetseg soum's centre in Khovd Aimag and renewable energy system Energy Authority of Mongolia; 2010j.

EAM. Detailed introduction about Bugat soum's centre in Govi-Altai Aimag and renewable energy system Energy Authority of Mongolia; 2010k.

EAM. Detailed introduction about Sevrei soum's centre in Umnugovi Aimag and renewable energy system Energy Authority of Mongolia; 2010l.

EAM. Detailed introduction about Bogd soum's centre in Uvurkhangai Aimag and renewable energy system Energy Authority of Mongolia; 2010m.

EAM. A field report on investigating technical problems occurred at renewable energy systems installed at centres of 12 remotely located soums in rural areas. Energy Authority of Mongolia; 2010n.

ESCAP. Mongolia: renewable energy report, economic and social commission for Asia and the Pacific, Asian and Pacific Centre for Transfer of Technology of the United Nations, 43; 2007. p. 15.

Foundation The Asia. Though improving: Mongolia still reeling under corruption. 2013. http://asiafoundation.org/in-asia/2013/12/11/though-improving-mongolia-still-reeling-under-corruption/, 2013. [[cited 2014 January 20]; Available from].

IEEJ. Country presentation: energy policy. Training and dialogue programs of JICA 2012. http://eneken.ieej.or.jp/data/4480.pdf, 2012. [[cited 2012 December 12]; Available from].

IRENA. Introduction of renewable energy sector in Mongolia and their policy environment. 2012. http://www.irena.org/DocumentDownloads/events/CopenhagenApril2012/8_%20J_Osgonbaatar.pdf, 2012. [[cited 2014 January 20]; Available from].

James P, Rizer, Garry Vollans. Contributions to Mongolian's sustainable energy strategy. USAID; 2002. p. 9–312.

Jamsranjav Chantsallkham. Sustainable rangeland management in Mongolia: the role of herder community institutions; 2009.

Maps of World. *Mongolia Latitude and Longitude Map*. [cited 2013 February]; Available from: http://www.mapsofworld.com/lat_long/mongolia-lat-long.html.

Maps.com. 2011. Political Map of Mongolia. 2011 [cited 2011 September]; Available from: www.maps.com.

Marion B, Rodri uez J, Pruett J. *Instrumentation for evaluating PV system performance losses from snow* in *American Solar Energy Society (ASES)*. 2009. Buffalo, New York: National Renewable EnergyLaboratory; 2009.

Martinot E. Renewable energy in Russia: markets, development and technology transfer. Renewable and Sustainable Energy Reviews, 1999, 3. 3; 1999. p. 49–75.

Martinot Eric. Renewable energy in developing countries—lessons learnt for the market. Energy Environ 2002;27:309–48. [2002].

Martinot E, Cabraal A, Mathur S. World Bank/GEF solar home systems projects: experience and lessons learned 1993–2000. Renew Sustain Energy Rev 2001;5(1):39–57. [2001].

Ministry of Power Energy, Resources Mineral. Power system master plan update. Bangladesh Government; 2006.

Modi V, McDade S, Lallement D, Saghir J. *Energy and the millennium development goals*, UNDP, UN millennium project, 22. World Bank; 2006. p. 8.

Nieuwenhout F, Dijk A, Hankins M, Wade H. Monitoring and evaluation of solar home systems: experiences with applications of solar PV for households in developing countries. Netherlands Energy Research Foundation; 2000.

NREC. *National renewable energy program* 2007. http://www.nrec.mn/en/index.php, 2007. [[cited 2013 February]; Available from].

NSO. National Statistical Office of Mongolia. 2011. http://www.nso.mn/v3/index2.php, 2011. [[cited 2012 November 12]; Available from].

Powers L, Newmiller J, Townsend T. Measuring and modelling the effect of snow on photovoltaic system performance. IEEE 2010:973–8.

REEEP. Renewable energy in Mongolia. 2012. http://toolkits.reeep.org/file_upload/10303046_4.pdf, 2012. [[cited 2012 December 12]; Available from].

REEEP. Renewable energy in Mongolia. 2012. http://toolkits.reeep.org/file_upload/10303046_4.pdf, 2012. [[cited 2012 2 February]; Available from].

REN21. Renewables interactive map—country profile: Mongolia 1. 2014. http://www.map.ren21.net/Mongolia_Renewables_Profile, 2014. [[cited 2014 20 January]; Available from].

Srinivasan S. Solar home systems: offering credit and ensuring recovery, solar energy society of India reports. Refocus 2005. http://www.refocus.net/features/archive/janfeb05/janfeb05_1_full.html, 2005. [[cited 2006 March 18]; Available from].

Surendra KC, Khanal Samir Kumar, Shrestha Prachand, Lamsal Buddhi. Current status of renewable energy in Nepal: opportunities and challenges. Renew Sustain Energy Rev 2011;15(8):4107–17.

UNCTAD. Renewable energy technologies for rural development. Current studies on science, technology and innovation. *United Nations Conference On Trade and Development*. 2010; 2010. [New York and Geneva].

Urmee Tania P, Harries David. A survey of solar PV program implementers in Asia and the Pacific regions. Energy Sustain Dev 2009;13(1):24–32.

Urmee Tania, Harries David, Schlapfer August. Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific. Renew Energy 2009; 34(2):354–7.

USAID. *Energy regulatory authority assessment report*. 2006. http://siINTINFANDLA/INTINFANDLAW/Resources/MongoliaERassessmentreport.pdf, 2006. [[cited 2013 January]; Available from].

USAID. Mongolia democracy and governance assessment. 2010. http://mongolia.usaid.gov/wp-content/uploads/Mongolia-DG-Assessment-Exec-Summary-FINAL-3-12-11.pdf, 2010. [[cited 2012 December 12]; Available from].

Whale J, M.P., McHenry A Malla. Scheduling and conducting power performance testing of a small wind turbine. Renew Energy 2013;55:55–61.

World Energy Outlook, World Energy. *Modern energy for all*. 2013. Paris, France: International Energy Agency; 2013.

Zhoua Wei, Loub Chengzhi, Lia Zhongshi, Lua Lin, Yanga Hongxing. Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. Appl Energy 2010;87(2):380–9.