The present work was submitted to the Faculty of Engineering

Designing an off-grid, battery-backed solar PV system for a gable roof cottage in Mongolia

Bachelor Thesis

by

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Ulaanbaatar/Nalaikh, 05.18.2023

Statutory Declaration

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

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Abstract

Global energy consumption is anticipated to increase by approximately 50% between 2018 and 2050, with the trend echoed in Mongolia, where annual electricity and heating demands are forecasted to grow at rates of 4.4% and 3.4% respectively up to 2030. This is prompting a transition towards renewable energy sources. The research focused on examining the feasibility of using off-grid photovoltaic (PV) solar systems for gable-roofed houses in Mongolia.

The research included an evaluation of solar potential in Mongolia and a comparative analysis of three different modeling platforms for PV system outputs. SolarGIS Prospect was identified as the most accurate tool, providing conservative results. With optimal tilt and orientation angles at 46° and 180° respectively, an 8.8kW PV system was found capable of meeting an average Mongolian household's electricity demand of 7.7kWp.

The PV system, integrated with an 8kW inverter and a 15kWh lithium-ion battery bank, yielded an annual power generation of 14,068 kWh against the consumption of 6730 kWh. However, a financial evaluation revealed the challenge of recovering the capital expenditure within the system's estimated lifetime, indicating the need for policy interventions such as tax cuts on auxiliary components.

Moreover, the study noted the benefits of using seamlessly functioning components like Huawei's fusion solar for ease of system monitoring. Future research should include comprehensive economic analysis and other renewable energy technologies to augment Mongolia's energy independence and environmental sustainability.

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Introduction

Global energy consumption is expected to grow by approximately 50% between 2018 and 2050 by the Energy Information Administration (EIA) (1). This trend is the same in Mongolia, the Asian Development Bank (ADB) forecasted that the electricity and heating compounded annual demand growth rates will be at 4.4% and at 3.4% up to 2030 respectively, and would eventually result in a **generation capacity shortage in 2023** (2). In recent times, the cost and availability of fossil fuels are on the rise, and this could lead to high prices due to limited access in the long term. Also, the effect of natural gas shortage due to Ukraine and Russian conflict demanded that OECD countries increase the use of fossil fuels, which is opposing their goal of reaching carbon neutrality by 2050. Consequently, numerous countries have developed policies to decrease their reliance on fossil fuels and lower energy expenses. In addition to that, Mongolia's current infrastructure is very poorly distributed and Majority of the land is not connected to the utility grid. Even though Mongolia has enormous fossil fuel reserves, logistics, and transportation is not developed across the country, which results in dependence on local non-fossil hard fuels in certain areas or imported electricity. Some areas are only accessible for electricity by scheduled times and the desire to supply domestic electricity demand itself is emerging.

Among those alternatives such as biomass, floating resources, and nuclear energy, socio-econ-technical requirements vary greatly and nuclear power station projects are facing strong resistance from both local and global level environmental activists and recent governmental and international acts to reduce further nuclear-radiating disposals. Also, biomass and biofuel products are mainly linked to their resources and location. Where there is a lot of agricultural waste is producing, there will be likely to establish biomass and biofuel production plants. In this case, both productions of energy from nuclear and biomass are non-viable in Mongolia due to a lack of resources and technical reasons (3).

The emphasis on using renewable energy sources has led to a shift towards cleaner energy with less impact on the environment compared to traditional sources. In 2018, renewable energy accounted for 26.2% of global electricity generation, and it is projected to increase to 45% by 2040, making it the fastest-growing source of electricity. Solar energy, which is an abundant and clean renewable energy source, is increasingly replacing non-renewable energy sources (4). Solar power is one of the most rapidly growing renewable energy sources, with the decreasing cost of solar panels and the implementation of various stimulus policies contributing to the growth of photovoltaic

(PV) energy. PV energy is considered a highly promising energy alternative due to its ubiquity and sustainability (5).

Numerous studies have identified suitable sites for PV power plants in recent years. A location suitable for solar installation depends on various factors, such as the amount of solar radiation received and technical, economic, environmental, and social factors, such as local topography, environmental impact, water availability, and urban development. Therefore, site selection for solar installation is not a simple process.

Mongolia possesses significant solar energy resources that could be utilized to enhance its energy security, reduce pollution, fulfill its global climate commitments, and develop regional electricity exports. However, in 2019 only 1% of total electricity was generated from solar energy. This research study will concentrate on designing an off-grid/standalone rooftop PV system for a gable-roofed house that will soon-to-be or planning-to-be constructed and assessing its capability for providing enough electricity for household demand. Also, beginner's guidelines for civilians about the optimum orientation angle of the building and roof angle as well as PV system sizing and economic estimation will be done for chosen setup for location. This study is considered a research study and will not include a detailed economic analysis like a preliminary or feasibility study. Many studies show that implementing fully standalone PV solar systems for household use results in lower IRR and ROI than hybrid or on-grid photovoltaic solar systems due to the relatively high price of a reliable battery bank. The study will determine whether rooftop PV solar systems can provide reliable electricity for households in remote areas where the utility grid is not accessible.

State of Art

2.1. Renewable Energy and Global Trend

Electricity generation sector experienced a slight decline in 2020 as a result of the COVID-19 pandemic. However, it rebounded by 5.4% in 2021 and is predicted to grow by 3.4% each year between 2022 and 2030 (6). Meanwhile, wind and solar generation continued to rise steadily, with wind generation increasing by 16% and solar generation increasing by 23% and reaching over tenth, 10.3%, of global electricity for the first time. Despite the growth in renewable energy sources, fossil-fired power plants remained the dominant source of electricity generation by producing 62% of global electricity (7). In the electricity generation mix, solar energy contribution is increasing faster than other resources in developed countries such as our southern neighbor the People's Republic of China, hereafter “China”.

Numerous countries worldwide, particularly members of the G-20, are taking steps towards reducing their reliance on fossil fuels and adopting renewable energy sources. Preliminary data compiled by BSW Solar, an industry federation, shows that in 2022, Germany's solar PV expansion surged by 28%, adding 7.2 GW of new installations to the grid. Especially, Roof-mounted installations for residential properties grew by 40%, reaching almost 3 GW. 2.65 million individual installations contributed to the total installed solar PV capacity of 66.5 GW by the end of 2022.

Figure 1. ***Rooftops PV systems on private houses, Duelmen, Germany***

Large ground-mounted solar array installations in the country supported by the Renewable Energy Act (EEG) increased by 70%, surpassing 2.4 GW, while installations built under power purchase agreements (PPAs) rose by 22% to 0.8 GW. Solar power contributed 12% to the net power production in Germany, producing nearly 62 TWh of output (8). Germany has a theoretical potential of 2.98 kWh/m² and a practical potential level of 2.96 kWh/m². The country has set an objective to phase out nuclear power and entirely transition to solar energy by 2050. Other nations with vast solar energy potential can look to Germany's efforts as a guide toward renewable energy adoption. China on the other hand planned to expand nuclear power plants dramatically in order to supply its surging economic growth.

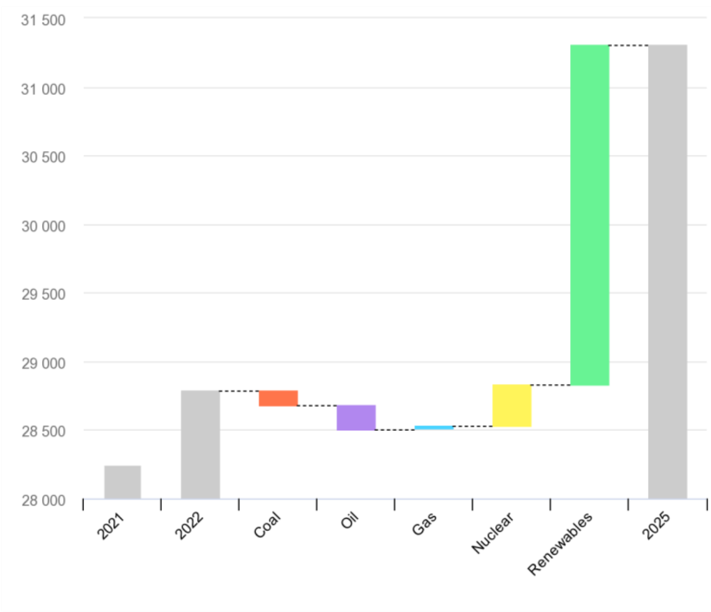


Figure 2. ***Changes in global electricity generation by source, 2021-2025***

From Figure 2 we can see that nuclear and renewable energy sources dominate in fulfilling a gap between the expected demand of 31,300 TWh of electricity in 2025 and 27,800 TWh in 2022.

(Source: IEA Report)

2.2 Solar energy

Solar energy is a form of renewable energy that is harnessed from the sun's radiation and converted into usable energy such as electricity or heat for society. Solar energy is harvested by solar panels/modules, which are composed of photovoltaic (PV) cells that capture the sun's energy from a photon form into electric energy. Another way to collect solar energy is through the use of solar thermal systems, which use mirrors or lenses to focus the sun's radiation onto a receiver that heats water, oil, salt, or even metal for direct use in heating applications or forming steam for turbines. Both solar PV and solar thermal systems are used to collect solar energy for similar applications but in different energy forms (9).

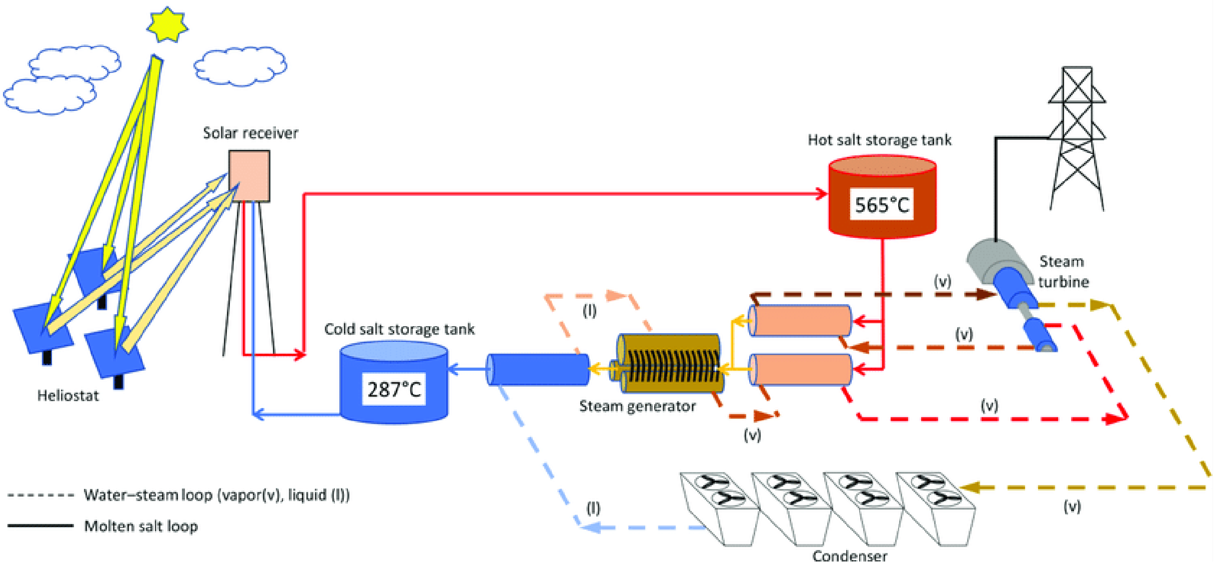


Figure 3. ***Scheme of concentrated solar power (CSP) tower system***

Figure 3 shows the general procedures of CSP. As we can see it is a complicated and resource-intensive plant. due to several subsequent processes to extract electricity efficiency is between 20% to 40% (10). We can see the photovoltaic systems scheme from 2.2.1. Sun is the most abundant and endless, in human-era, source of energy available on Earth, with an estimated 10,000 TW of solar energy reaching the planet's surface daily. Considering the current consumption rate, the projected growth in the next two decades, and the amount of solar radiation received in just one hour, the potential of solar energy is enormous. In fact, the potential for solar energy to meet the global energy demand is 5,000 times greater than the current consumption rate. Therefore, developing more solar energy projects could be a sustainable solution to meet the growing energy demand in the future. The International Renewable Energy Agency (IRENA) estimates that the global technical potential of solar PV and solar thermal energy is 100,000 terawatt-hours (TWh) per year. This is more than 20 times the global energy demand in 2019. The report also estimates that solar PV and solar thermal energy could provide 23% of the world's electricity by 2050.

2.2.1 Photovoltaic solar system principle

A photovoltaic (PV) cell, also known as a solar cell, is power electronic that converts the energy from sunlight directly into electricity through a process called the photovoltaic effect. The photovoltaic effect is a phenomenon that occurs when photons from sunlight strike the surface of a semiconductor material, such as silicon, and cause the release of electrons from the material's atoms. These electrons then flow through an electrical circuit attached to the material, producing an electric current that can be used to power electrical devices or stored in batteries for later use (11).

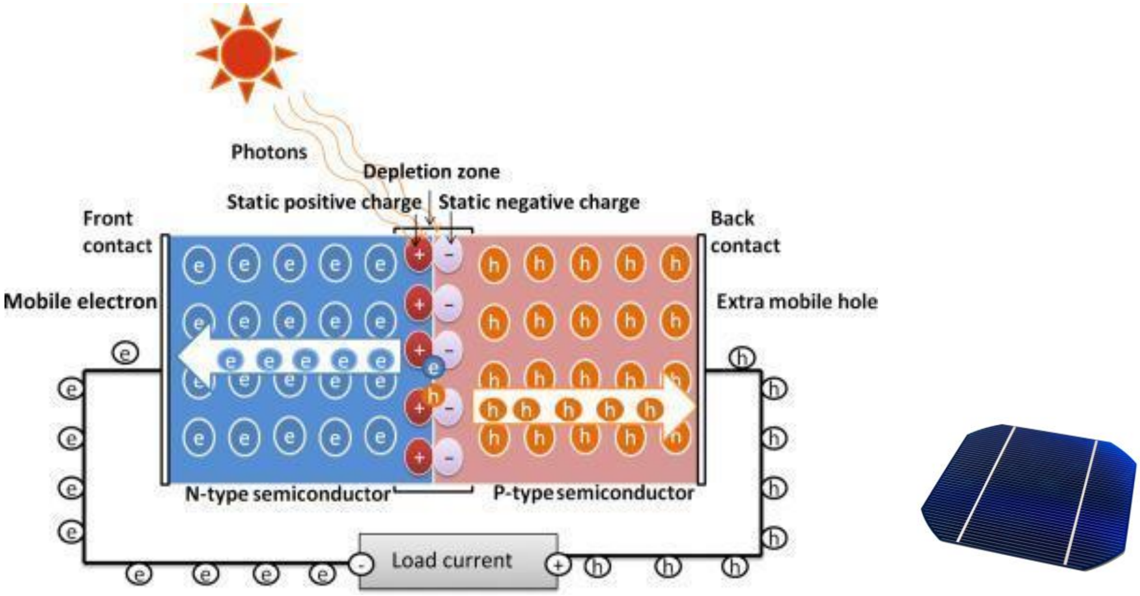


Figure 4. ***Photovoltaic effect on solar cells***

The PV cell is made up of two or more layers of semiconductor materials, which are usually silicon-based. When sunlight beam contacts on the PV cell, it is absorbed by the semiconductor material, causing electrons to be released and creating a flow of electricity. Multiple PV cells are typically combined into modules, which can be used to generate larger amounts of electricity.

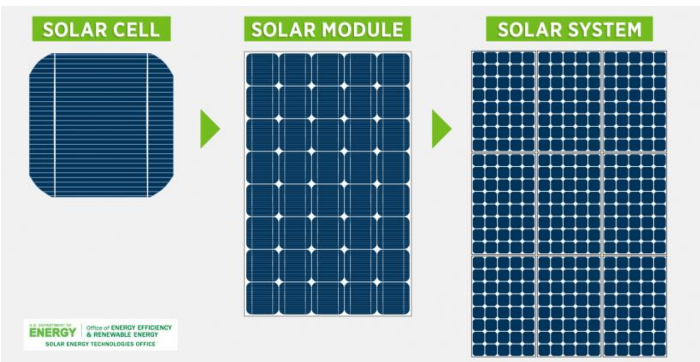


Figure 5. ***PV cell, PV module, PV solar system distinction***

2.2.2 PV module types

PV module price has decreased dramatically over the past decade due to technological advancements and economies of scale in manufacturing. According to a report by the International Renewable Energy Agency (IRENA), the average global price of PV modules decreased by around 90% between 2010 and 2020, from $3.8/W to

$0.35/W. However, prices can vary based on factors such as module efficiency, manufacturer, and installation costs.

There are 4 main types of PV modules that are commercialized and used daily. there are a lot more underdevelopment or yet-to-be-commercialized PV modules that are promising to achieve even greater efficiency and lead the solar energy sector on top of energy production. these 4 types are the following:

2. Monocrystalline: These panels are made from a single, high-purity silicon crystal and have the highest efficiency (up to 20%) and the longest lifespan among all PV module types. However, they are also the most expensive.
3. Polycrystalline: These panels are made from multiple silicon crystals and have a lower efficiency (around 16-18%) compared to monocrystalline panels. However, they are more affordable.
4. Thin-film: These panels are made from thin layers of semiconductor materials, cadmium telluride, copper indium, amorphous silicon, or cadmium telluride gallium selenide, and have the lowest efficiency, approximately 10-13%, but the lowest cost among all PV module types. However, this type of panel could be flexible and frameless, which makes it more portable and favorable to micro-usage.
5. The passive emitter and rear cell (PERC) are a monocrystalline-type solar cell that has higher efficiency and lower costs compared to traditional monocrystalline cells. PERC cells have a passivation layer on the rear surface that reduces energy loss caused by recombination and improves cell electrical performance. This technology allows lighter to be absorbed by the cell, resulting in higher energy output and efficiency, up to 25%.

Table 1. ***Information of various PV solar modules***

Solar Cell Type	Efficiency Rate	Advantages	Disadvantages
Monocrystalline Solar Panels (Mono-SI)	~20%	High-efficiency rate; commercially optimized; high lifetime value	Expensive
Polycrystalline Solar Panels (p-Si)	~17%	Lower price	Prone to high temperatures; lower lifespan & slightly less space efficiency

Thin-Film: Amorphous Silicon Solar Panels (A-SI)	~7-13%	Relatively low costs; easy to produce & flexible	shorter warranties, shorter lifespan
Passivated Emitter and Rear Cell (PERC)	~25%	Very high performance & efficiency rate	Complex manufacturing; expensive

Thin film panels aside, most PV modules have an expected lifespan of approximately 25 years. These panels are tested under standard conditions, which involve exposure to 1000 W/m² of solar radiation, an ambient temperature of 25°C, and an air mass of 1.5 (equivalent to 1 sun) at sea level for determining their electrical performance. After testing under standard test conditions (STC), solar panels get their nominal peak watts, Wp, but the actual power output produced by a PV panel may either exceed or fall below its rated peak watts due to a variety of surrounding environmental conditions (12). PV modules can be arranged in series or parallel, depending on the desired output. While parallel connections offer higher currents, shadow effects or weaker parallel strings can cause significant issues. Series connections, on the other hand, are typically more independent and can be connected using a power box.

2.2.3 PV solar systems

A grid-connected photovoltaic system is a type of power generation system that is connected to the utility grid and consists of solar panels, inverters, and equipment to establish a connection to the grid. Such systems are commonly used in residential, commercial, and larger-scale setups. Unlike off-grid solar power systems, grid-tied systems typically do not require battery backup, as any excess energy generated by the system is automatically transferred to the linked utility grid. In residential setups, grid-connected rooftop systems usually have a capacity of around 10 kilowatts, which is typically sufficient to meet the household's energy requirements. Any excess power generated by the system can be fed back into the grid for use by other connected consumers. The transferred power is tracked using a meter. In cases where the PV system generates less energy than the household requires, energy can be drawn from the grid.

According to the International Energy Agency, the worldwide installed capacity of grid-connected PV systems was around 580 GW at the end of 2018. This capacity is projected to triple by 2030, making grid-connected PV systems a critical component of global efforts to transition to renewable energy sources. Studies have shown that grid-connected PV systems can be cost-effective, reduce greenhouse gas emissions, and contribute to energy security. However, issues such as grid stability, intermittency, and power quality may need to be addressed in order to fully integrate grid-connected PV systems into existing electrical grids.

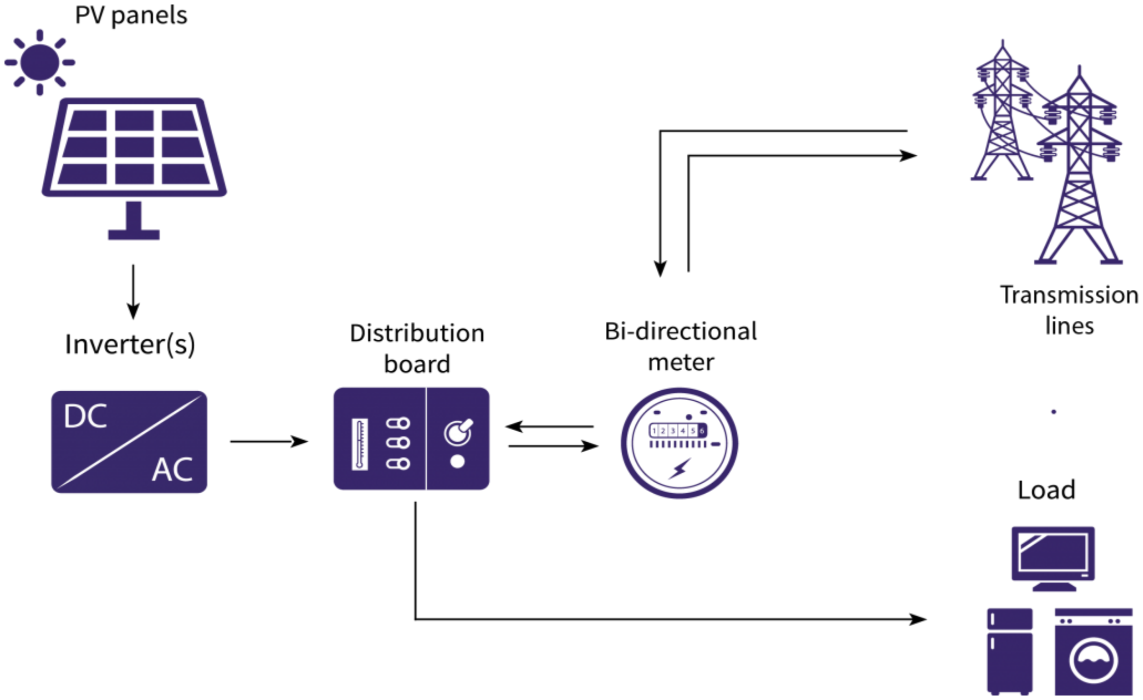


Figure 6. ***On-grid/grid-connected system's operation scheme***

An off-grid system, also referred to as a standalone or mini-grid system, is a self-sufficient electricity supply system that is not connected to the utility grid infrastructure. Off-grid systems are often used in remote and rural areas where it is too costly or impractical to connect to the central grid. They also offer alternative energy sources to grid-connected systems in areas with unreliable or inadequate grid power supply. Off-grid systems usually rely on renewable energy sources, such as solar, wind, or hydropower, for electricity generation.

Off-grid systems are typically composed of various components, including electricity generation sources (e.g., solar panels), energy storage systems (e.g., batteries), inverters, charge controllers, and optional backup generators. These components work together to ensure that the electricity supply is stable, reliable, and sufficient to meet the demand of the load. However, designing and operating off-grid systems can be challenging due to their complex and dynamic nature (13).

In conclusion, off-grid systems are a promising solution for providing electricity to remote and underserved areas. They offer a reliable and sustainable electricity supply that is independent of centralized grid systems. However, designing and operating these systems require careful consideration of various technical, economic, and social factors.

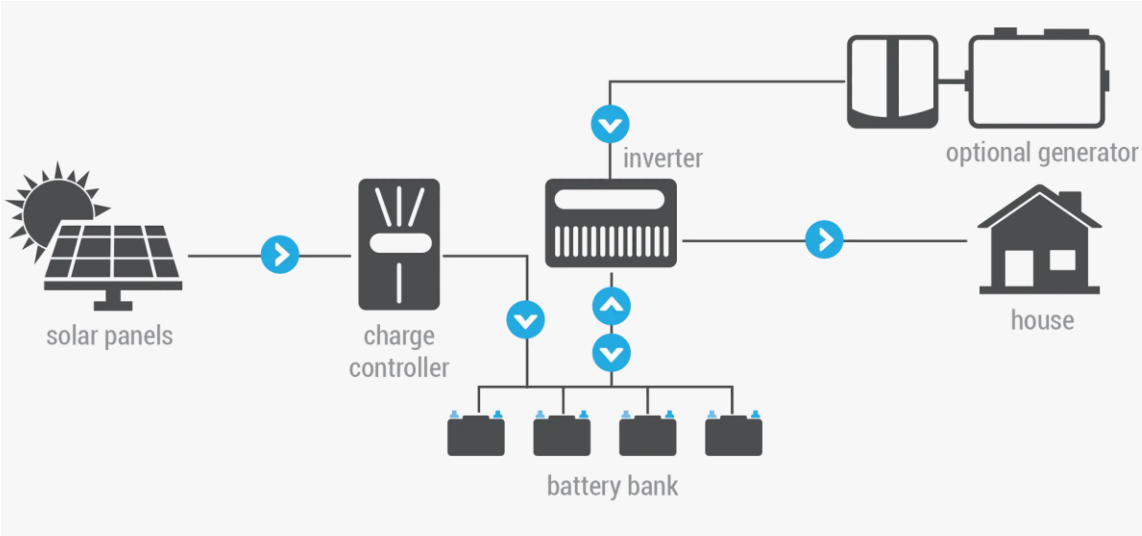


Figure 7. ***Off-grid/stand-alone solar system operational scheme***

A PV hybrid system is a combination of photovoltaic (PV) solar panels and another power generation source, typically a battery or a generator. The hybrid system utilizes both renewable and non-renewable energy sources to optimize power production and increase energy reliability.

In a PV hybrid system, the solar panels generate electricity during the daytime when there is sunlight, while the battery provides power when the solar panels are not generating electricity, such as during the night or when there is less sunlight. The battery can store excess energy generated by the solar panels during the day for use later when solar production is lower. This reduces the dependency on the grid and enables energy independence. PV hybrid systems are commonly used in off-grid areas or in locations with unreliable power supply, as they can provide reliable and continuous power.

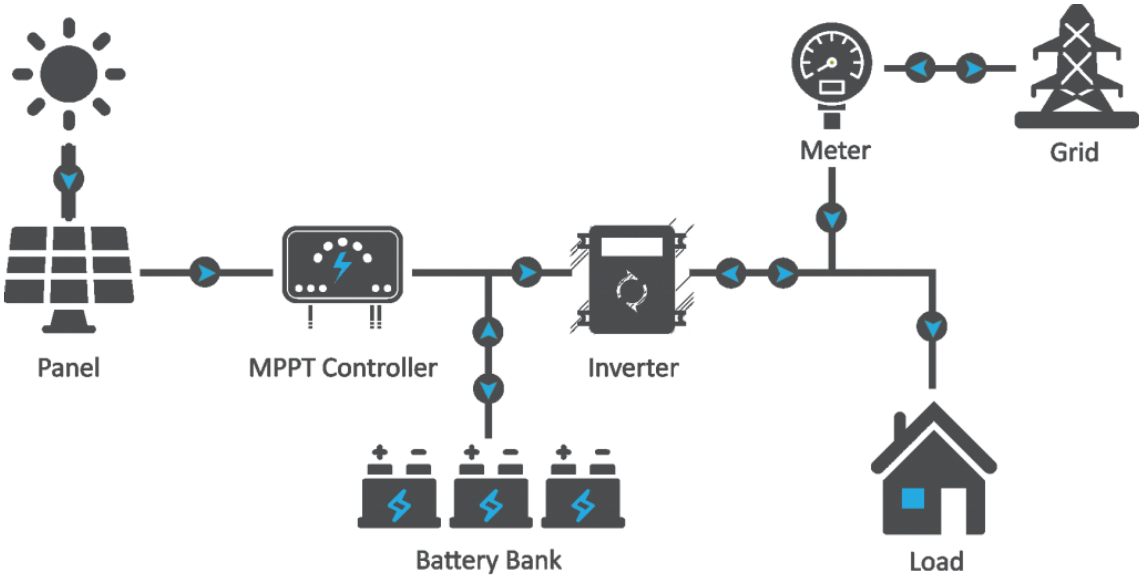


Figure 8. ***Hybrid solar system operation scheme***

They are also gaining popularity in grid-connected systems, as they can reduce electricity bills by storing excess energy during low usage periods and discharging it during peak hours when electricity rates are higher. It has advantages such as it does not require a big battery bank like the off-grid system because it is also connected to the grid and could export excess electricity to the grid by feed-in-tariff rates. However, this system is possible in areas where there is a utility grid (14).

Table 2. ***Various PV solar system component comparison***

Required components	**On-grid PV solar system**	**Hybrid PV solar system**	**Off-grid PV solar system**
PV modules	✓	✓	✓
Charge controller	✓	✓	✓
Inverter	✓	✓	✓
Battery bank	X	✓	✓✓
Bi-directional meter	✓	✓	X

2.2.4 PV mounting systems

To ensure the longevity and stability of a PV array, it must be installed on a durable and secure structure capable of withstanding various environmental factors, including wind, rain, hail, and corrosion, for several decades. The structure also tilts the PV array at a fixed angle depending on the latitude, orientation, and electrical load requirements. Rack mounting is currently the most popular installation method, owing to its robustness, versatility, and ease of construction and installation. Nonetheless, more advanced and cost-effective methods are constantly being developed.

For ground-mounted PV arrays, tracking mechanisms are available that automatically move panels to follow the sun across the sky, which results in greater energy production and higher returns on investment. One-axis trackers move modules from east to west, while two-axis trackers keep them directed toward the sun throughout the day. Tracking involves higher upfront expenses and more maintenance, particularly for advanced systems. However, as systems have improved, the cost-benefit analysis increasingly favors tracking for ground-mounted systems.

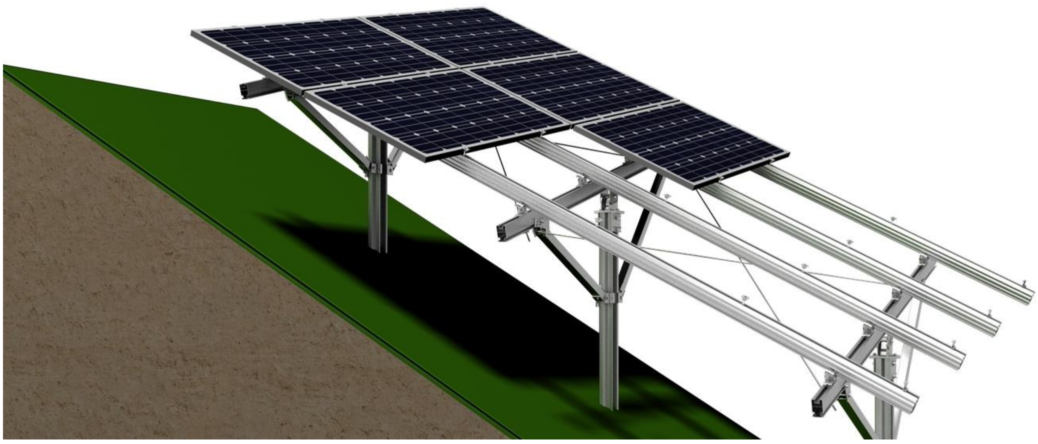


Figure 9. ***Ground-mounted PV solar system***

Our main area of focus is on roof-mounted solar panel systems, with particular emphasis on gable roofs. Installing solar panels on a flat or linearly inclined roof is typically easier and less complex. A roof with a slope provides the added advantage of shielding the panels from strong winds and gusts, which can cause damage. Additionally, a sloped roof structure helps prevent snow accumulation on solar panels during the winter months. Also, the study could neglect the calculation of the frame structure to withstand wind force.

Figure 10. ***Rooftop PV system on a gable-roofed house***

There have been several studies on the benefits of roof-mounted solar panel systems, particularly for residential properties. A study conducted by the National Renewable Energy Laboratory (NREL) found that rooftop solar panels have the potential to provide a significant portion of electricity needs in urban areas. Additionally, a study by the University of California, San Diego, found that installing solar panels on residential roofs could potentially offset a significant amount of carbon emissions.

Furthermore, research has also been conducted on the impact of various roof materials and configurations on the performance of solar panel systems. A study published in the Journal of Solar Energy Engineering found that the type of roofing material and orientation significantly impacted the energy output of solar panel systems. Therefore, careful consideration of roof design and materials is crucial for optimal performance and energy production of rooftop solar panel systems (15).

2.2.5 Off-grid PV solar system component

Inverter is the most important power electronic of the off-grid solar system, aside from PV panels, that converts the direct current (DC) into alternating current (AC). Inverters are essential because the PV system generates DC that cannot be used directly for the household’s daily appliance which uses AC to operate. It is classified into two classes. String/central inverters are used to connect a set of panels to a single inverter, which then converts the DC power generated by the system’s DC to AC. Although cost-effective, this setup can result in reduced power production if any individual panel in the string is shaded or damaged (16).

In contrast, microinverters are smaller inverters that are installed on each individual PV module. With a microinverter, shading or damage to one panel will not affect the power production of the others, but the overall cost of the system may be higher. Both string and microinverters can benefit from a system that manages how the solar system interacts with any attached battery storage(17).

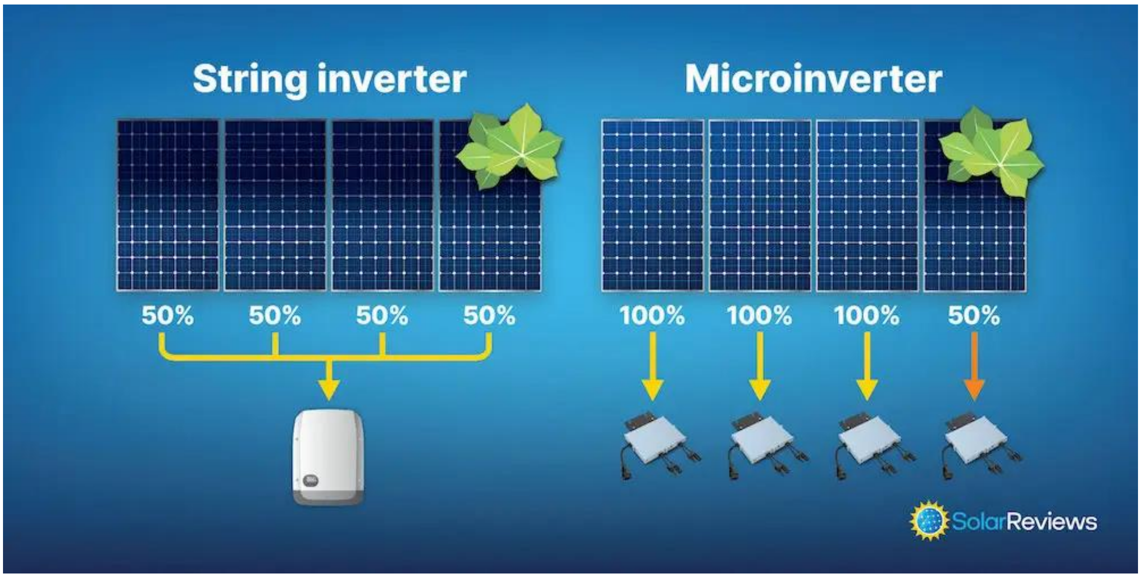


Figure 11. ***Illustration of a string inverter and a microinverter performance under shading effect***

A charge controller is an electronic device that regulates the electricity flow between the solar panels and the battery, as well as the battery and the load. It prevents issues such as overcharging, deep discharging, and overvoltage. By controlling the voltage and current from the panels, it ensures efficient charging of the battery while preventing overcharge. It also safeguards against deep discharging by limiting the battery's discharge level. There are two types of charge controllers, Pulse Width Modulation (PWM) and Maximum Power Point Tracker (MPPT). PWM is best suited for single panels so it is not necessary to take it out seriously. however, on the other hand, MPPT is very crucial for off-grid systems due to its functionality. The last thing people want from their PV system is a damaging battery from overcharging or discharging completely. all this can be avoided by using MPPT for the system. Also, MPPT ensures to use of full power generation for charging the battery which eventually results in quicker charging time (18). some research indicated that using MPPT can increase the efficiency of solar system by up to 30% but higher initial up-front costs can be problematic. however, modern inverters include MPPT in their modules

Optimizer, also known as a power optimizer is a module-level power electronic that converts unregulated DC output into steady PC output that can be useful. this operates with a simple inverter and can be beneficial to detect any error on a specific module or minimize the shading effect. Working architecture is the same as a string inverter but module-level monitoring is added.

Table 3. ***Pros and cons of an inverter and optimizer***

Inverter types	**Pros**	**Cons**
String inverters	Easy to maintain Reliable, proven Low cost	Only string-level monitoring and MPPT Difficult to expand the system size without buying a new inverter
Power optimizers	Individual panel MPPT is a great solution to partial shading Panel-level monitoring available Panel-level rapid shutdown	Difficult to expand the system size in the future without buying a new inverter Difficult to maintain with partial electronics on the roof
Microinverters	Individual panel MPPT is a great solution to partial shading Panel-level monitoring available Panel-level rapid shutdown Easy to expand system size in the future Safer, low operating AC voltage compatible with the grid	Most expensive Difficult to maintain due to electronics on the roof

The battery bank is one or more batteries connected for serving as energy storage and increasing the reliability of the system by balancing electricity generation and consumption fluctuations, converting and conserving excessive energy during daytime into chemical energy. For small and commercial scale, new battery technologies such as solid-hydrogen batteries, flow-battery and sodium-based batteries are under development, and the market is dominated by lithium-ion batteries for their high energy density and longevity, and lead-acid batteries for their affordability. however, even with the much higher up-front cost of installing lithium-ion battery, the lifespan of lithium-ion type outweighs lead-acid battery (19).

Table 4. ***Comparison of lithium-ion batteries and lead acid batteries***

	LITHIUM-ION	**LEAD ACID**
Cost	$$$	$
Capacity	15+ kWh	1.5-5kWh
Depth of discharge	90%	50%
Efficiency	95%	80-85%
Lifespan	10-15 years	3-8 years

2.3 Mongolia

Mongolia, with a land area of over 1.5 million square kilometers and a population of 3.45 million, is currently the world's least densely populated country. Its economy relies heavily on the mining and agricultural sectors, with nomadic herders constantly moving their livestock to find optimal grazing lands and shelter for each season. Located between longitudes 87° and 120°E and latitudes 41° and 52°N, Mongolia is a landlocked country situated between China and Russia. Its continental climate results in four distinct seasons characterized by large temperature fluctuations between daytime and nighttime. Despite low temperatures, minimal precipitation, and over 250 sunny days annually, Mongolia's climate presents excellent opportunities for harnessing solar energy but still relies heavily on coal-fired Combined Heat and Power (CHP) plants for the majority of its electricity production (20). Some of these CHP plants are located near major urban areas to meet the high heating demand during winter, causing significant problems with local air pollution. The capital of Mongolia, Ulaanbaatar, has been designated as one of the world's most polluted cities by the World Health Organization (21). The country's dependence on coal has resulted in relatively high per capita greenhouse gas (GHG) emissions, with a value of 8.3 tCO2eq, surpassing those of many European countries.

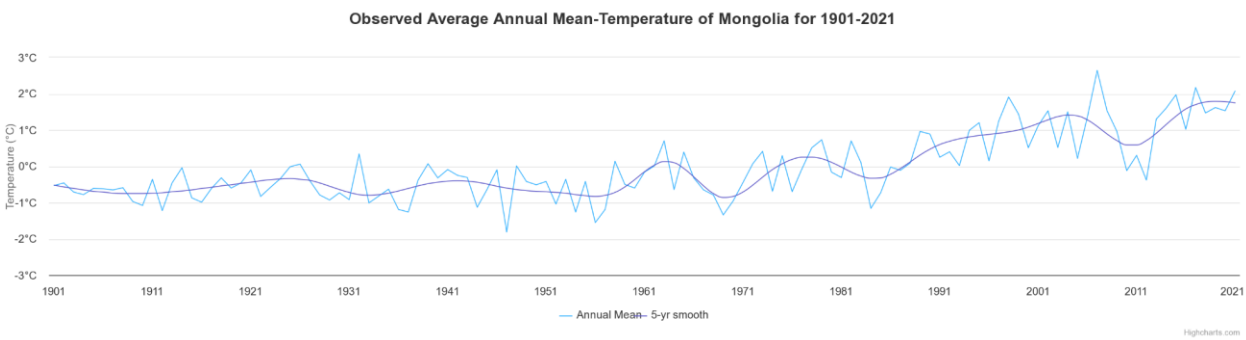


Figure 12. ***Observed average annual temperature of Mongolia (1901-2021)***

The observed average mean temperature (Figure 12) is rising but about 1° degree Celsius which could enhance the efficiency of solar panels.

Another important factor is global horizontal irradiation (GHI), also known as theoretical solar potential map shown below. It is the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance, and ground-reflected radiation and measured in kWh/m² (kilo-watts per square meter) (22). Average GHI of 4.29kWh/m² is ranked 43th among other countries.

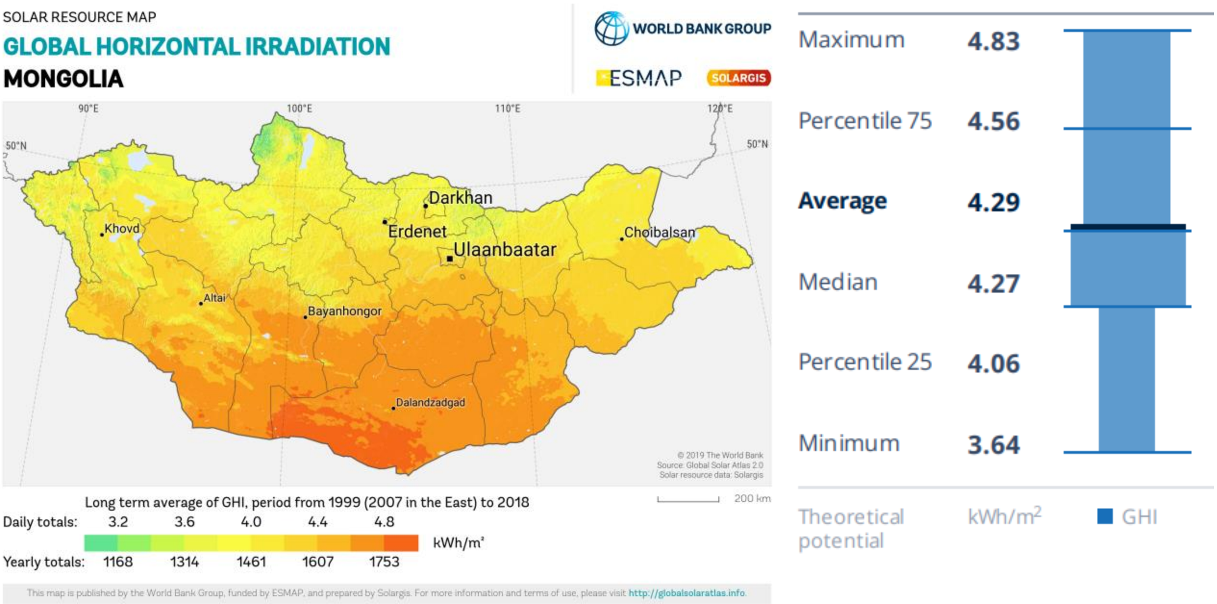


Figure 13. ***Global Horizontal Irradiation (GHI)Map of Mongolia and average value***

2.3.1 Electricity sector

The total electricity consumption of Mongolia reached 9 TWh 81% of which was supplied by domestic generation sources and 19% of which was provided by power imports by China and Russia and distributed by 5 energy system, which are The Central Energy System (CES), Western Energy System (WES), Altai-Uliastai Energy System (AUES), Eastern Energy System (EES) and Southern Energy System (SES).

By 2019, total installed capacity of electricity generation is 1476.6 MW consisting of 1162.2 MW CHPs (combined heat and power plants), 155 MW Wind Power Plants, 60MW Solar Power Plants, 26.21 MW Hydro Power Plants, and 72.6 MW Diesel Power Plants. Table below shows the detailed name of plants and its sources.

Table 5. ***Mongolian electricity generation by source and plants***

Generation source	Name of plant	Installed capacity
Fossil fuel (Coal-fired)	CHP #2	24 MW
	CHP #3	186 MW
	CHP #4	749 MW
	Darkhan CHP	59 MW

	Erdenet CHP	28.8 MW
	Choibalsan CHP	53 MW
	Dalanzadgad CHP	36 MW
	Ukhaahudag PP	9 MW
Wind	Salkhit WPP	50 MW
	Tsetsii WPP	50 MW
	Sainsanshd WPP	55 MW
Solar	Darkhan SPP	10 MW
	Monnaran SPP	10 MW
	Gegeen SPP	15 MW
	Bukhug SPP	15 MW
	Sumber SPP	10 MW
Hydro	Taishir HPP	11 MW
	Durgun HPP	12 MW
	Other minor hydro stations	3.21 MW

5 energy distribution systems deliver energy to 60% of population who live in Soum center, Province center and 97% of major cities' population. However, during peak heating season people tend to use electric heater as an additional heating source beside central heating due to lack of heating and it results in peak electricity demand at the same time (23).

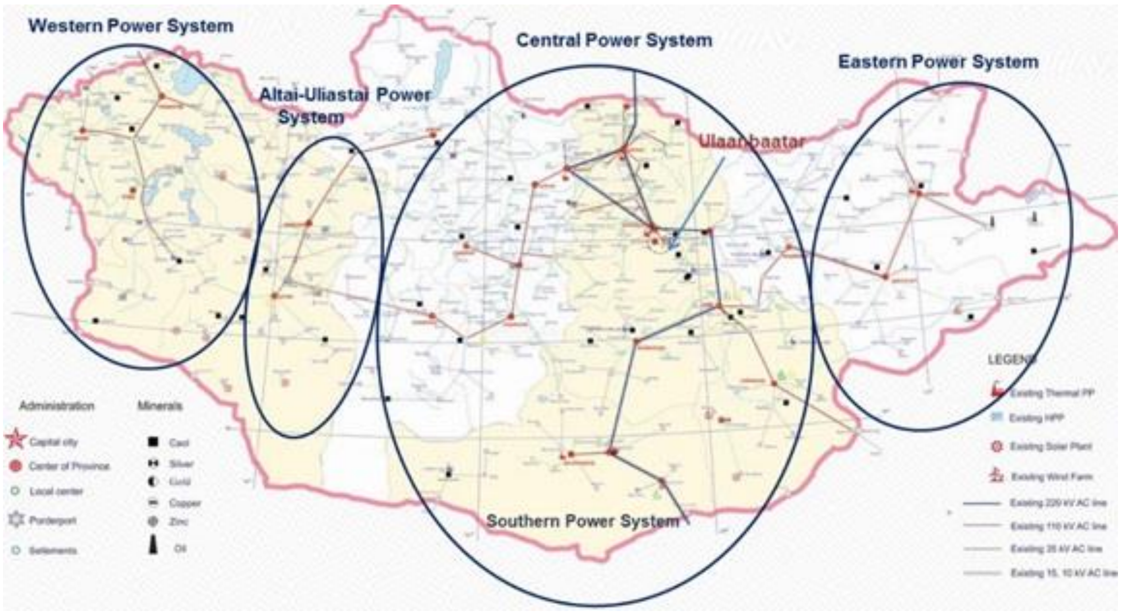


Figure 14**. *Energy distribution systems***

2.3.2 Solar energy potential

Mongolian wind and solar power potential combined is estimated to be equivalent to 2,600 gigawatts (GW) and other study shows, technical wind and solar potential is around 7.25 TW capacity and 12.17 PWh/year of electricity (21). Also, latest study uses GIS system to evaluate suitability of both wind and solar energy implementation and concluded economic potential of ground-mounted PV is 5.12 TW and rooftop PV is 1.11 GW. In addition to that, 118 484 km² is considered as suitable for ground-mounted PV system and 27 km² is suitable for rooftop PV system (20). This study was on nation-level and considered 20% of rooftop area in Ulaanbaatar is suitable for rooftop system.

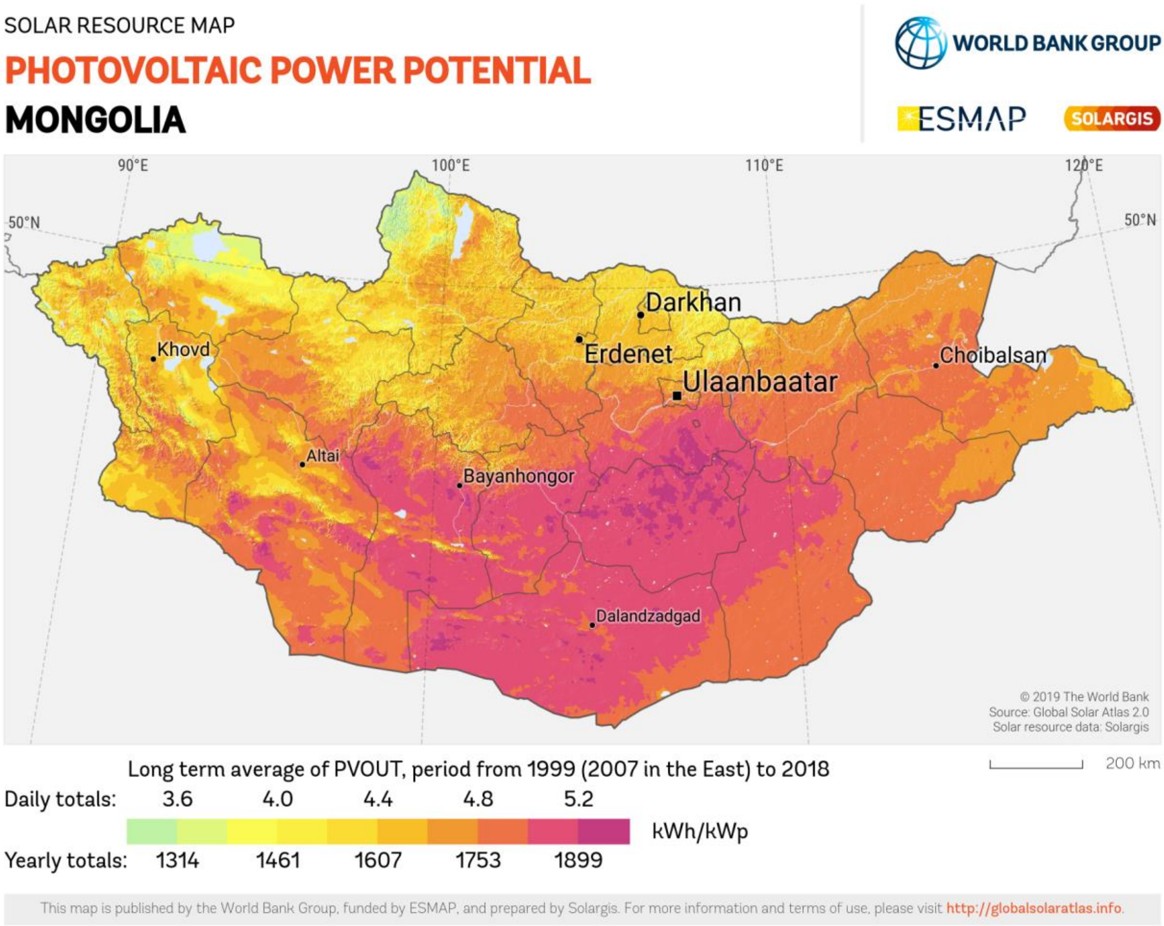


Figure 15. ***Long term average PVOUT (1999-2018)***

A geospatial hot spot analysis using a Geographical Information System (GIS) can help indicate areas that are suitable for developing renewable energy projects. This type of analysis can also be used to assess the potential of renewable energy sources on a city, national, or even global scale.

2.3.3 Regulatory Framework and Legislation

Mongolian government is actively seeking ways to boost renewable energy production and has established a goal of achieving a renewable electricity target of 30% of total capacity by 2030. To support this objective, a Feed-in Premium (FiP) was implemented in 2015, whereby renewable energy generators receive the difference between the market price and the set FiP compensation. Mongolian Energy Regulatory Commission (ERC) manages and regulates the electricity tariff per kilowatt hour, also known as the market price for electricity.

Net metering is a billing system that credits solar energy system owners for the electricity they add to the grid. This billing system provides opportunities for residents who have renewable energy sources such as PV solar systems to export excess electricity to the grid. A bi-directional meter that measures both imported electricity and exported electricity is required for this system. Electricity bills can be positive which means customers use more electricity from the grid than electricity given back to the grid. Customers could get credit or generate income if their electricity imported electricity to the grid exceeds the amount of electricity used from the grid. For doing that resident's solar system has to pass all technical requirements and make a contract.

Until 2019, June households and renewable energy producers could sell energy from the solar system to the central grid at feed-in-tariff between 0.15$/kWh and 0.18$/kWh (24). After 2019, the feed-in tariff was set to 0.12$/kWh (25). This reduction in feed-in-tariff led to a significant decrease in the adoption of residential PV solar systems. Also, Mongolian Energy Regulatory Commission put threshold that households can feed up to 50% of electricity generated to the grid.

Methodology

For comprehensive data research, data acquisition is an important step, and the databases need to be carefully selected. International Renewable Energy Agency (IRENA), BP Amoco, Eurostat, International Energy Agency (IEA), Bloomberg New Energy Finance (BNEF), and Google Scholar search engine are used as the data sources in this study because the data sources are professionally devoted to the field. Accessible on the official website of the relevant statistical departments and authoritative institutions, which provide search functions for official documents.

Also, GIS and SolarGIS Prospect have best available data and simulation architects for evaluating viability or performing prefeasibility analysis based on database that they have been collected and updated since 2010.

Global Solar Atlas (globalsolaratlas.info) is online platform, designed for preliminary solar system assessment and free version of SolarGIS Prospect and I performed same analysis on selected location and result was identical except it does not include some detailed graphs, figures and features. Both platforms can assess solar energy potential on global, country, regional and specific location level.

Result of SolarGIS Prospect and Global Solar Atlas's results were checked by PVWatts powered by NREL.

The keywords to search for influential official documents included “renewable energy”, “PV solar system”, “off-grid system”, “renewable energy in Mongolia”, “rooftop system”, “gable roof”, “PV system design”, “simulation” and related items. The publications of relevant statistical departments and authoritative institutions publications that developed the statistics of greenhouse gas emissions, the changes in primary energy consumption, the practice of global energy transition, the statistics of renewable energy, and other statistics are considered strongly related to the focuses of this paper.

System sizing and simulation

4.1 Load calculation

Load calculation is based on average household's appliance (26) and each household appliance are selected on its energy efficiency. It is about building house with off-grid system so it is recommended to choose energy efficient home appliances for daily usage in order to reduce energy consumption from the start.

Weekly energy consumption using nominal wattage of each appliance:

$$Energy\ \ consumption\ (kWh)$$
$$= Wattage\ of\ appliance(W) *\ Weekly\ operating\ house(hours)/1000$$

Annual energy consumption:

$$Annual\ energy\ \ consumption\ (kWh) = Weekly\ consumption(kWh) * 52\ weeks$$

Annual cost to run the appliance using the following formula:

$$Annual\ cost\ to\ run\ appliance\ (kWh)$$
$$= Annual\ consumption(kWh) * Utility\ rate\ per\ kWh$$

Peak load of household, weekly and annual electricity consumption calculated by applying equations above on table below.

Table 6**. *The peak load and annual energy consumption calculation based on household appliance***

Appliance	Quantity	Wattage (W)	Operation hours per week	Weekly electric consumption (kWh)	Annual electric consumption (kWh)
Lighting bulb	4	40	42	6.72	349.4
LED bulb	12	8	42	4.03	209.6
Washing machine	1	500	42	21	1092
Iron	1	1500	1.5	2.25	117
Vacuum	1	1200	0.5	0.6	31.2
TV	1	65	35	2.28	118.3
Satellite box	1	12	35	0.42	21.8

WIFI router	1	18	168	3.02	157.25
Laptop	1	65	15	0.98	50.7
Charger	2	20	21	0.84	43.7
Boiler	1	2000	10.5	21	1092
Pump	1	100	14	1.4	72.8
Induction stove	1	1500	17.5	26.25	1365
Rice cooker	1	500	3	1.5	78
Large Fridge	1	180	168	30.24	1572.5
		7708			**6370**

From the table, we can see that all appliances together require power of electric system to be greater than 7.7kWp and 6370kWh of electricity will be used annually. For system sizing later, we have to be conservative on selecting inverter and solar system.

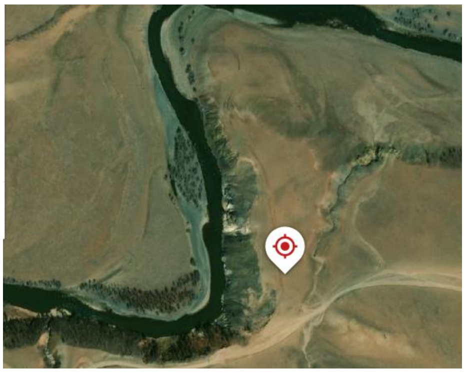
4.2 Location study

To showcase the viability of this study, a specific site was chosen and a rooftop solar system was meticulously designed for a gable roof configuration. The site was selected based on its location, which is situated more than 400 meters away from high-voltage powerline. Furthermore, a comprehensive price offer has been received, estimating the required investment for new powerline and electrical equipment necessary for connecting to the existing infrastructure line to be approximately 100 million MNT. In detailed, this price was for purchasing 35/10kV, 10/0.4kV transformators, powerline and poles. However, the implementation of the housing project itself has been postponed due to the perceived high costs associated with constructing an entire house solely for the purpose of establishing a power line. Here is the detailed information about selected location.

Location: Bat-Ulzii Soum, Uvurkhangai Province, Mongolia

Geographical coordinates 46.892517°, 102.381089° (46°53'33", 102°22'52")

Figure 16. ***Detailed view of selecten location***



Time zone: UTC+08, Asia/Ulaanbaatar

Elevation: 1654 m

Land cover: Sparse vegetation (<15%)

Terrain slope: 8°

Location on the map: [Click here]

Average temperature is 1.0°C, and monthly average temperature is ranged between -18.2°C, in January and 17.7°C, in July.

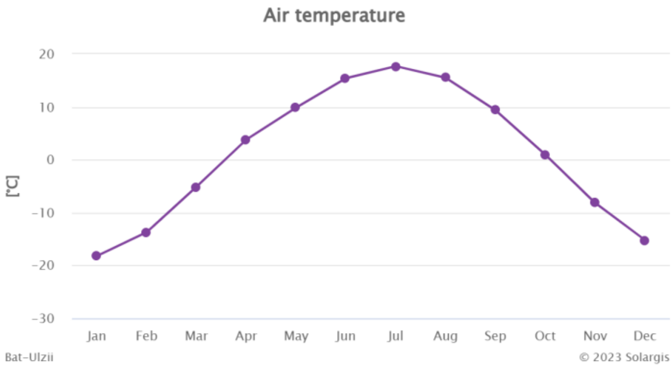


Figure 17. ***Monthly average temperature of site***

4.3 System sizing and selection

We have opted to design a house measuring 8 meters by 10 meters with a gable roof, as this size aligns with the average dimensions of cottages in our context. In the literature review, it was determined that the optimal tilt angle for PV panels is typically based on the latitude of the location. Therefore, for Mongolia, the ideal tilt angle falls within the range of 41° to 52°. However, constructing a roof within this range, particularly between 41° and 51°, may pose challenges. Additionally, the platforms utilized in this study possess a feature that facilitates the determination of the optimal tilt angle for the system, with results primarily ranging from 43° to 48°. However, after conducting numerous assessments in various locations across Mongolia, the prevailing tilt angle was found to be 46°. Consequently, we have concluded that the optimal roof angle for a gable-roofed house is 45°. Furthermore, the orientation angle of the house should face south (180°) for all locations in the northern hemisphere.

Based on this information, we have calculated the useful area of the roof by determining its length, which measures 10.6 meters, and its width, which measures 5.95 meters.

equation 1. $Area = length * width$

The area of the roof facing south is calculated to be 63.07m². However, considering practicality and the need for maintenance and service access, it is necessary to leave a minimum space of 30 to 40 cm from the top and bottom edges, as well as 50 cm from the other ends of all edges. As a result, the usable area is reduced to 49.44m², with dimensions of 9.6m by 5.15m.

For the installation of solar panels, Clean Resource Development (CRD) LLC has recommended the use of 16 BSM560M10-72HPH modules, each with a power rating of 550W. These modules have dimensions of 2278mm by 1134mm, with 5cm spacing between each module. In total, this system will occupy an area of 43.15m², utilizing 87.3% of the total useful roof area.

equation 2. $Installed\ capacity = number\ of\ modules * module\ rating(W)$

$$Installed\ capacity = 16\ panels * 0.55\ kWp = 8.8kWp$$

The installed capacity of our solar system is 8.8kWp, which represents the nominal value under standard conditions. However, considering the favorable surroundings of the PV system, including factors such as high albedo, abundant sun exposure, and clear air, it is expected that the PV system will be capable of producing more power than its rated capacity. Therefore, it is crucial to choose an inverter with a capacity exceeding 8.8kWp to accommodate this potential power generation.

Based on the extensive experience of Clean Resource Development engineers, Huawei's power electronics have demonstrated excellent performance in the Mongolian climate. Furthermore, Huawei offers user-friendly features that allow for convenient monitoring and control of the solar system, ensuring that users can easily manage and optimize its operation. Consequently, we have chosen the Huawei SUN2000-8KTL-M1 inverter as our preferred option. It has a rated power output of 8kW or 8.8kVA, which aligns well with the installed capacity of our system. This inverter is specifically designed to handle power up to 12kW from the PV array, allowing for effective management of power distribution between the load and the battery. The Huawei SUN2000-8KTL-M1 inverter is equipped with comprehensive protection protocols to ensure the safety and efficiency of the system. It includes features such as reverse charging protection, overcharge protection, and overvoltage prevention. These measures help safeguard the components of the system and prevent any potential damage.

Considering the surroundings of our selected location, where there are no shading elements like trees or buildings, the use of an optimizer is optional. Optimizers are typically employed to mitigate the impact of shading or module-level variations in performance. However, since shading is not a significant concern in our case, the integration of Maximum Power Point Tracking (MPPT) technology within the inverter itself is sufficient to optimize the performance of the PV array.

When it comes to selecting a battery bank, it is evident that lithium-ion batteries outperform other options such as lead-acid batteries. Although the initial cost of lithium-ion batteries may be higher, they offer advantages such as greater depth of discharge and longer cycle life, surpassing the performance of lead-acid batteries. Additionally, lithium-ion batteries do not pose health risks associated with lead exposure or acid leakage, eliminating the need for a dedicated battery storage room.

In line with our selection of the Huawei SUN2000-8KTL-M1 inverter, Huawei also offers a modular and expandable battery bank ranging from 5kWh to 30kWh. This battery bank is compatible with the inverter, ensuring seamless integration and optimal performance. For our specific requirements, we have chosen a 15kWh capacity battery bank to ensure sufficient energy supply during nighttime periods.

Table 7. ***System sizing and critical components***

Component	**Module**	**Quantity**	**Rated power/capacity**	**Total Power capacity**
PV module	550W BSM560M10-72HPH	16	550 W	8.8 kWp
Inverter	SUN2000-8KTL-M1	1	8 kW	8 kW
Battery	LUNA2000-15-S0	1	15 kWh	15 kWh
PV Optimizer* (optional)	SUN2000-(600W-P)	16	600 W	9.6 kW

In the Technical Drawing included in the Appendix, you will find the detailed part list, including wiring, fuses, circuit boxes, mounting parts, and sealers, required for the implementation of the system.

Figure 18. ***Technical drawing part for PV array (full scheme in Appendix)***

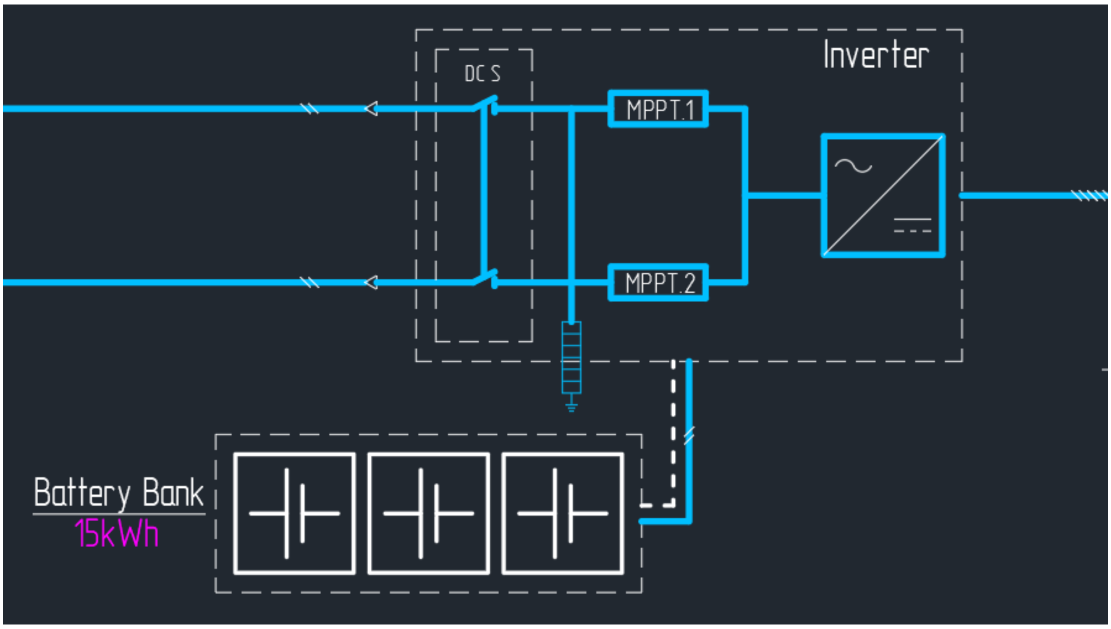


Figure 19**. *Technical drawing part for a string inverter and battery bank***

All Huawei parts, including the selected inverter and battery bank, are accompanied by a comprehensive warranty package. The components come with a 10-year factory warranty, providing coverage for any potential manufacturing defects or malfunctions during this period. In addition, Huawei offers a performance warranty lasting for 25 years, ensuring that the components will maintain their specified performance levels over an extended duration. This warranty coverage reflects Huawei's commitment to the quality and reliability of their products, providing customers with peace of mind regarding the long-term performance and durability of the system.

4.4 Simulation

Simulations were performed using three different platforms: SolarGIS v 1.16.1 (SolarGIS Prospect), GSA 2.8 (GlobalSolarAtlas.Info), and Website Version 8.1.0 utilizing the PVWatts® API version 8.0. The purpose of these simulations was to verify the accuracy of the results and determine which platform would be most suitable for beginners.

Each platform allows users to input the coordinates of the site manually or utilize the integrated maps for location selection. Once the site coordinates are set, users need to provide the PV system configuration to conduct the assessments. For the comparison, a small rooftop PV system was selected on both SolarGIS Prospect and GlobalSolarAtlas.Info, with adjustments made to change the default setting from a 1kWp system to an 8.8kWp system. It should be noted that all platforms calculate the results based on c-Si (crystalline silicon) PV modules.

Table 8. ***Results retrieved from 3 platform***

	SolarGIS Prospect	GlobalSolarAtlas.Info	PVWatts
Annual total photovoltaic power output (kWh)	**14,068.4**	**14,068**	**15,125**
Daily specific PV power output	**4.380**	**N/A**	**N/A**
DNI (kWh/m^2 per day)	**5.324**	**5.528**	**N/A**
GHI (kWh/m^2 per day)	**4.186**	**4.236**	**N/A**
DIF (kWh/m^2 per day)	**1.340**	**1.349**	**N/A**
GTI opta (kWh/m^2 per day)	**5.378**	**5.486**	**N/A**

SolarGIS Prospect provides more comprehensive and detailed information about the selected areas compared to Global Solar Atlas. Both platforms, SolarGIS Prospect and Global Solar Atlas, present similar results, indicating a level of consistency between the two in terms of the simulation outcomes.

On the other hand, PVWatts yields significantly higher results and does not provide as much additional information such as mean temperature, elevation, and optimum tilt angle. It is important to note that PVWatts is primarily focused on estimating energy production and may not offer the same level of detailed information as the other platforms.

SolarGIS Prospect shows system configuration as follows:

Installed capacity: 8.8kWp • c-Si - crystalline silicon (mono or polycrystalline)

Azimuth: 180° • **Tilt**: 45°

Small inverter [95.9% Euro efficiency]

System loss: DC cabling 1 % • DC mismatch 0.8 % • AC cabling 0.2 % • Monthly soiling losses up to 4.5 % • Monthly snow losses up to 0.0 %

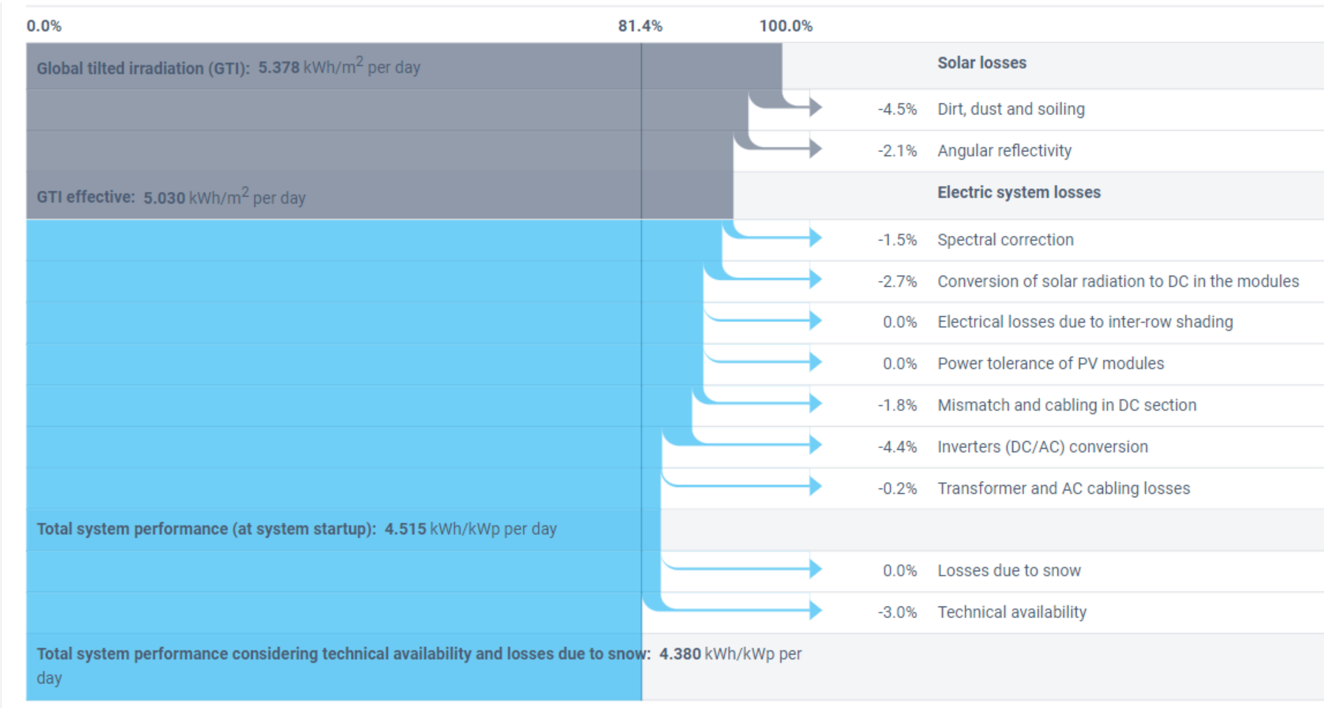


Figure 20. ***System loss details***

Table 9. ***Monthly theoretical PV electricity potential of PV system***

Month	GTI kWh/m^2 per ...	PVOUT speci... kWh/kWp pe...	PVOUT total kWh	PR %
Jan	4.259	3.820	1,042.0	89.7
Feb	5.499	4.756	1,172.0	86.5
Mar	6.525	5.416	1,477.5	83.0
Apr	6.473	5.183	1,368.3	80.1
May	6.276	4.893	1,334.8	78.0
Jun	5.688	4.357	1,150.2	76.6
Jul	5.492	4.181	1,140.6	76.1
Aug	5.704	4.388	1,197.1	76.9
Sep	5.985	4.736	1,250.4	79.1
Oct	5.319	4.399	1,200.1	82.7
Nov	3.818	3.311	874.2	86.7
Dec	3.525	3.158	861.4	89.6
Yearly	**5.378**	**4.380**	**14,068.4**	**81.4**

4.5 Economic analysis

When designing and planning an off-grid residential PV solar system, a key consideration is the levelized cost of electricity (LCOE). The LCOE represents the average cost of electricity generated over the system's lifetime and is derived from the total lifetime cost and the total energy generated.

To calculate the lifetime cost of the PV system, you need to sum up the capital expenditure (CAPEX) and the net-present value of the operation and maintenance (O&M) costs. However, for small residential-scale systems, the maintenance cost is typically negligible. It is assumed that all components used in the PV system can perform reliably until the end of the expected lifetime, which is usually around 25 years. Therefore, the focus is primarily on estimating the capital expenditure of the system.

To assist with estimating the capital expenditure, CRD LLC, a company specializing in PV system installations from industrial to residential levels, provided you with the latest prices of components and installation fees. These prices will be instrumental in determining the upfront costs associated with the PV system. By combining the estimated capital expenditure with the total energy generated during the system's lifetime, you can calculate the LCOE and assess the cost-effectiveness of the residential PV solar system.

Table 10. ***8.8kWp PV system implementation quotation from CRD LLC***

Component	Module	Quantity	Unit cost (MNT)	Cost (MNT)
PV module	550W BSM560M10-72HPH	16	760,000	12,160,000
Inverter	SUN2000-8KTL-M1	1	4,300,000	4,300,000
Battery	LUNA2000-15-S0	1	32,310,000	32,310,000
Electric box		1	2,950,000	2,950,000
Miscellaneous (wiring, mounter, etc.)			1,500,000	1,500,000
Mounting system			4,000,000	4,000,000
Installation service			4,000,000	4,000,000
			Cost	61,220,000
			VAT	4,476,000
exchange rate: 1$ equals 3,500MNT			**Total cost**	**65,696,000**

Total implementation cost is around 18,800$ and system is projected to produce 14,068.4 kWh annually and 342812.9 kWh for lifetime. SolarGIS Prospect depreciated PV system efficiency yearly and calculated how much energy system is estimated to produce.

equation 3. $LCOE = lifetime\ cost\ of\ system / total\ energy\ produced\ by\ system$

$$LCOE = 18{,}800\ \$\ /\ 342812.9\ kWh = 0.055\ \$/kWh$$

It is bit higher than utility electricity rate which is approximately 0.38 $/kWh. However, it still better than spending 100 million MNT for connecting to high-voltage powerline which is 400m distant.

Solar Prospect generated financial analysis such as IRR, ROI and LCOE on emphasis of electricity generated is fed back to grid at rate of 0.12 $/kWh.

Result and discussion

Our study has studied on PV solar systems and Mongolia's solar potential, taking into account the current situation and the Mongolian government's goal of achieving 20% renewable energy generation by 2030. At present, renewable resources contribute approximately 3 to 5% of the total electricity demand in Mongolia. This lower percentage could be attributed to factors such as changes in feeding tariffs and the instability of the currency, which have slowed down investment in renewable energy. However, advancements in technology and the mass production of components (such as inverters, PV modules, optimizers, MPPT, and batteries) have led to reduced prices, making solar energy more affordable and cost-effective.

Solar energy has emerged as one of the cheapest sources of electricity, enabling countries to work towards their goals of achieving zero carbon emissions by 2050. For instance, in Germany, citizens are increasingly installing rooftop solar systems with the support of government funding and initiatives. Despite Germany having lower levels of global horizontal irradiation and fewer sunny days compared to Mongolia, it has not hindered the adoption of PV systems for households.

In countries like Canada, snowfall can pose challenges as it accumulates on the roof. Flat roofs can be disadvantageous due to potential leakage and limited thermal insulation. In Mongolia, gable roofs are simple yet effective, as the trapped air between the gable roof and the floor provides additional thermal insulation, and snow accumulation and leakage are less problematic if the roof has a steep slope. Through our research, we have determined that the optimum angle for PV system installation on the roof is between 42° and 51°, with 45° being the most efficient angle. Although this angle may not be visually pleasing, it is necessary to achieve maximum efficiency. Wind speed and direction calculations are not necessary as they are generally close to the roof surface.

Recent studies have utilized GIS databases to identify suitable areas for PV system installations. After excluding urbanized, steep, and distant locations from the existing electricity grid, it has been determined that approximately 23.7% of the area in Mongolia is suitable for PV system implementation.

Shading can have a considerable impact on the performance of photovoltaic systems, resulting from factors such as leaves, snow, or shadows cast by objects in the surroundings. To minimize the negative effects of shading, it is important to design the house in such a way that the roof facing the southern side is free from obstacles like chimneys or ventilation pipes. However, it is crucial to evaluate potential external factors that could cause shading on the site itself, as each location is unique.

In our selected location, there are no nearby trees or objects that could cause shade on the roof. As a result, the use of an optimizer was considered optional. However, if there are any shading factors present, it is recommended to employ an optimizer to achieve maximum output from the photovoltaic system, even in the presence of shading. Optimizers can mitigate the impact of shading on individual PV modules, allowing the system to operate more efficiently and generate higher overall energy production. The selection of electric components for the PV system was based on calculating the load of the household, which is 7.7kW. The components were selected in the following order: inverter, PV module, optimizer, and battery bank. The chosen system is fully capable of supplying the household's load at any time, ensuring that the electricity demand is met consistently.

The monthly average electricity generation from the PV system is estimated to be 1100kWh, while the monthly average electricity consumption of the household is 530kWh. This indicates that the PV system is generating more electricity than is consumed by the household, resulting in surplus energy. We take conservative approach because off-grid households may need to use more appliance or power tools.

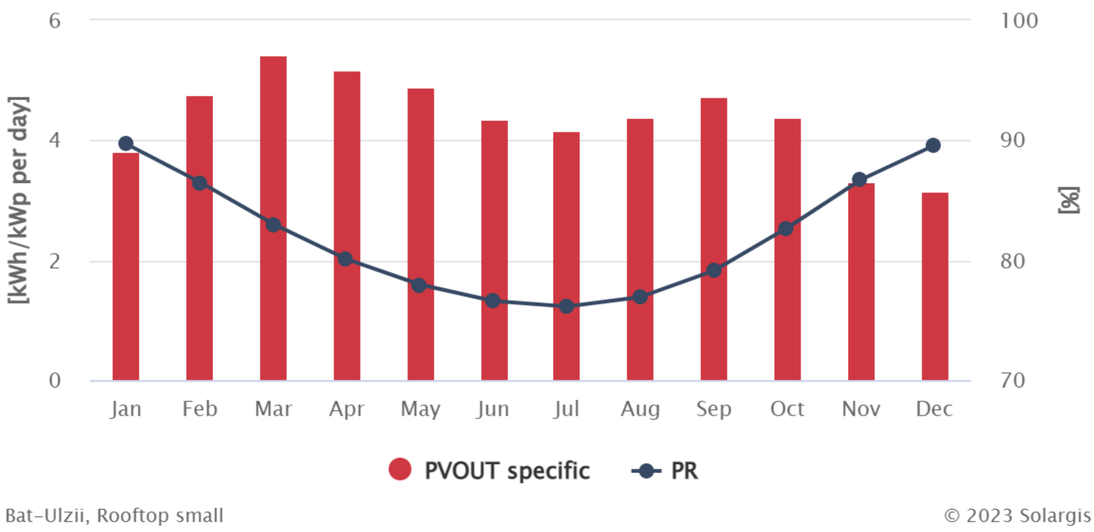


Figure 21. ***Monthly specific power output (PVOUTspecific) and Performance ratio (PR)***

The temperature effect on the PV system impacts its efficiency. Winter increases performance ratio due to lower temperatures, while lower solar elevation decreases irradiation intensity. Peak power generation is observed in March and September, attributed to temperature drop and optimal solar elevation. During summer, high solar elevation and module temperature above 25°C result in temporary efficiency decrease. Proper measures can mitigate temperature effects and ensure optimal performance throughout the year.

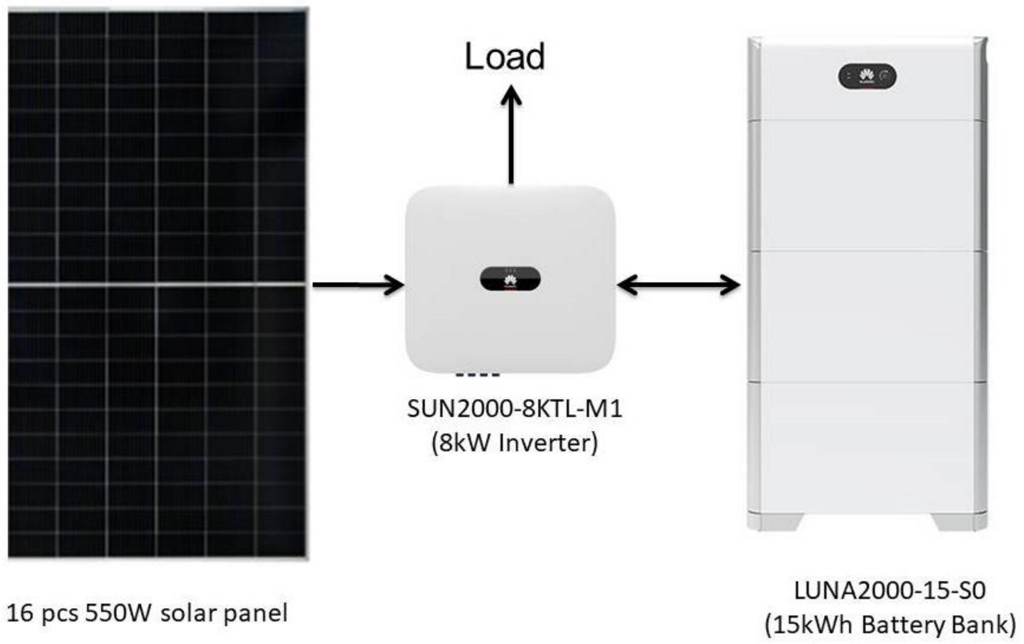


Figure 22. ***A simple scheme of chosen PV system***

Table 11. ***Comparison of two alternative energy sources***

	8.8kWp rooftop solar system	**Alternative source (connecting to high-voltage powerline)**
Upfront cost ($)	18,800	28,900
Maintenance	very low	low
Electricity bill	No bill for next 25 years	0.0376 $/kWh used
Reliability	Independent	Dependent on grid

$$LCOE = 0.055\ \$/kWh$$

Although the cost of electricity generated by the PV solar system may be slightly higher than the utility electricity rate of approximately 0.0376 $/kWh, it is still a more cost-effective option compared to spending 100 million MNT to connect to a high-voltage powerline that is 400 meters away. Additionally, by having a PV solar system, you can avoid monthly electricity bills.

SolarGIS Prospect's financial analysis feature diagnosed that selected system has ROI 89.07% and IRR 6.49% which means revenues generated by exporting electricity generated cannot cover initial investment in lifetime of 25 years under linear depreciation on equity about 4%. Apart from the economic benefits, there are also intangible benefits associated with an off-grid PV solar system. It provides electricity independence, allowing you to build your dream project houses in any location, regardless of the existing infrastructure. The system also offers reliability, as you are not reliant on the grid and its potential power outages. Moreover, by using solar energy, you contribute to the reduction of carbon emissions, promoting a more sustainable and environmentally friendly approach to energy generation.(27)

Conclusion

This study aims to evaluate the feasibility of meeting the average electricity demand of a typical Mongolian household using an off-grid PV solar system installed on an average-sized gable-roofed cottage. The research includes an assessment of Mongolia's solar potential and the analysis of PV solar system outputs using three different platforms.

Based on the findings, it is concluded that using GIS-based modelling platforms provides more accurate results. These platforms utilize more precise databases and offer the flexibility to customize system details, resulting in improved accuracy in assessing the performance of rooftop PV systems for average households in Mongolia. The SolarGIS Prospect platform is found to provide the most conservative and accurate results among the three platforms analyzed. It offers a range of features that enhance the accuracy of the simulations. Based on the simulation results, the optimum tilt angle for the solar panels is determined to be 46° for the specific location with coordinates 46.892517°, 102.381089° (46°53'33", 102°22'52"). The house should be oriented towards the south (180°) to maximize solar energy capture. Utilizing 87% of the useful roof area which is tilted at 45°, a PV system with an output of 8.8kW can easily meet the household's load of 7.7kWp. This is achieved by integrating the system with an 8kW inverter and a 15kWh lithium-ion battery bank, ensuring a reliable and efficient power supply.

Projected annual power consumption is 6730kWh and power generation is 14,068kWh. It enables household, to use all electric appliances during the while charging a battery bank fully. However, financial analysis showed rooftop PV system installer is not able to cover capital expenditure during estimated lifetime.

To boost adoption of solar system, government should take some action like reduce tax rates on auxiliary component such as high ampere wire, optimizer, specific mounting racks, bi-directional meters. Choosing components primarily depends on the load, inverter, and intended battery bank capacity. It has also been found that investing in components that function seamlessly, such as Huawei's fusion solar, can considerably simplify monitoring. Scanning the QR code for the battery bank, inverter, or optimizer using a mobile device or website system will result in automatic integration. This facilitates system control and monitoring from an interface that's easy to use.

The energy demand in the future will be co-accelerated by rapid industrial growth and population growth. Reduction of Mongolia’s power infrastructure carbon footprint and increasing share of renewable energy is crucial for ensuring electricity independence, reliability and improving air quality in urbanized areas.

SolarGIS Prospect and Global Solar Atlas seem to be more suitable for obtaining detailed information about selected areas, while PVWatts is more focused on energy production estimation. Depending on the specific needs and preferences of the user, each platform may serve a different purpose and provide varying levels of information and functionality. Furthermore, future research could include other renewable energy technologies, such as concentrated solar and geothermal generation for heating purpose, since the research focuses on electricity.

Appendix

Өвөрхангай аймаг, Бат-Өлзий сум

АМИНЫ ОРОН СУУЦ

8кВт нарны цахилгаан үүсгүүр суурилуулах ажил

(Ажлын зураг: Хүчит төхөөрөмжийн хэсэг - ХТ)

БОЛОВСРУУЛСАН.

Гүйцэтгэсэн...Т.Дашнамжил

Улаанбаатар хот 2022 он

МАТЕРИАЛЫН ТҮҮВЭР

МАТЕРИАЛЫН ТҮҮВЭР – 1

№	Нэр	Маяг	Хэмжих нэгж	Тоо ширхэг	Тайлбар
1	Нарны зай хураагуур 550Вт		ком	16	
2	DC/AC инвертер 8кВт		ком	1	
3	Нөөцлүүрийн гаралтын модуль 5кВт		ком	1	
4	Нөөцлүүр 5кВт/ц		ком	3	
5	Автомат таслуур DC Circuit Breaker MCB, 32A, 600VDC		ком	2	PV to Inverter
6	Гадна зориулалтай 4ф автомат суух жижиг хайрцаг		ком	1	
7	Айлын самбар – (АС), IP-31 а. Оролтын автомат: ВА47-29, 4р, 32А – 1ш б. Шугамын автомат: АД12, 2р, 25А, 30mA – 4ш АД12, 2р, 25А, 10mA – 1ш ВА47-29, 2р, 16А – 1ш		Ком	1	AC
8	Нарны зай хураагуурын холбогч MC4		ком	8	
9	4мм2 хөндлөн огтлолтой зэс голтой нарны зай хураагуурын кабель (улаан)		метр	30	
10	4мм2 хөндлөн огтлолтой зэс голтой нарны зай хураагуурын кабель (цэнхэр)		метр	30	
11	6мм2 хөндлөн огтлолтой зэс голтой ПВХ тусгаарлагатай кабель	ПВ-3	метр	10	Inv to Load
12	10мм2 хөндлөн огтлолтой зэс голтой ПВХ тусгаарлагатай кабель	ПВ-3	метр	15	
13	Уян пластмассан хоолой ф16мм		метр	100	
14	Уян пластмассан хоолой ф22мм		метр	10	
15	Уян пластмассан хоолойн холбох муфт ф16мм		ширхэг	15	
16	Кабелийн төгсгөвч 4-6мм2		багц	1	
17	Кабелийн төгсгөвч шулуун 6мм2		ширхэг	10	
18	Кабелийн төгсгөвч шулуун 10мм2		ширхэг	10	
19	Цахилгааны лент		ширхэг	3	

МАТЕРИАЛЫН ТҮҮВЭР – 2

№	Нэр	Маяг	Хэмжих нэгж	Тоо ширхэг	Тайлбар
20	Багцлагч L300мм		уут	1	
21	Төмөр утас		боодол	1	
22	Төмрийн шруп 2.5см хэмжээтэй		хайрцаг	1	
23	Тэлэгч шруп 6мм-н		уут	1	
24	Боолт 12см, м8		ш	20	
25	Гайка		ш	20	
26	Шайба		ш	40	
27	Тосон хар будаг		ширхэг	10	
28	Силикон хар		ширхэг	4	
29	Unistrut 40*40мм, 3мм		м	24	
30	Нарны зай хураагуурын дундын дарагч		м	28	
31	Нарны зай хураагуурын захын дарагч		м	8	

Өвөрхангай аймаг, Бат-Өлзий сум АМИНЫ ОРОН СУУЦ					
Материалын түүвэр					Үе шат А.3
Инженер			ЕГ Шифр	Масштаб	Огноо 2023-05
Гүйцэтгэсэн		Т.Дашнамжил	ТГ Шифр	Зургийн дугаар ХТ-2	Бүх хуудас 7
Шалгасан					

ЕРӨНХИЙ ҮЗҮҮЛЭЛТ

Системийн ерөнхий үзүүлэлт

Нарны зай хураагуур	
Нарны зай хураагуурын суурьлагдсан чадал	8.8 кВт
Системийн хүчдэл (В)	329.6 В
Гүйдэл (А)	13.11 А
Дундажаар нарны зай хураагуурын хоногт үйлдвэрлэх цахилгаан (кВт/ц)	37.2 кВт/ц
Нарны зай хураагуурын суурьлуулах өнцөг	45 градус
Инвертер	
Нэрлэсэн чадал (Вт)	8 кВт
Хүчдэлийн түвшин (В$_{ac}$)	380 В
Давтамж (Гц)	50 Гц
Нөөцлүүр	
Нөөцлүүрийн багтаамж (Вт/ц)	15кВт/ц

Хүчдэл хувиргагчийн техник үзүүлэлт

Тогтмол хүчдэлийн оролт	
Оролтын хамгийн их чадал	12000 Вт
Нарны зай хураагуурын хамгийн их хүчдэл (В)	1100 В$_{dc}$
Ажиллах хүчдэлийн хүрээ (В)	140 – 980 В$_{dc}$
Эхлэх хүчдэл (В)	200 В$_{dc}$
Оролтын хамгийн их гүйдэл (А)	19.5 А
Хувьсах хүчдэлийн гаралт	
Чадал (Вт)	8800 Вт
Гаралтын хамгийн их гүйдэл (А)	16.7 А
Гаралтын хүчдэл (В)	220 В$_{ac}$ / 380 В$_{ac}$
Давтамж (Гц)	50 / 60 Гц

Нэгж нарны зай хураагуурын техник үзүүлэлт

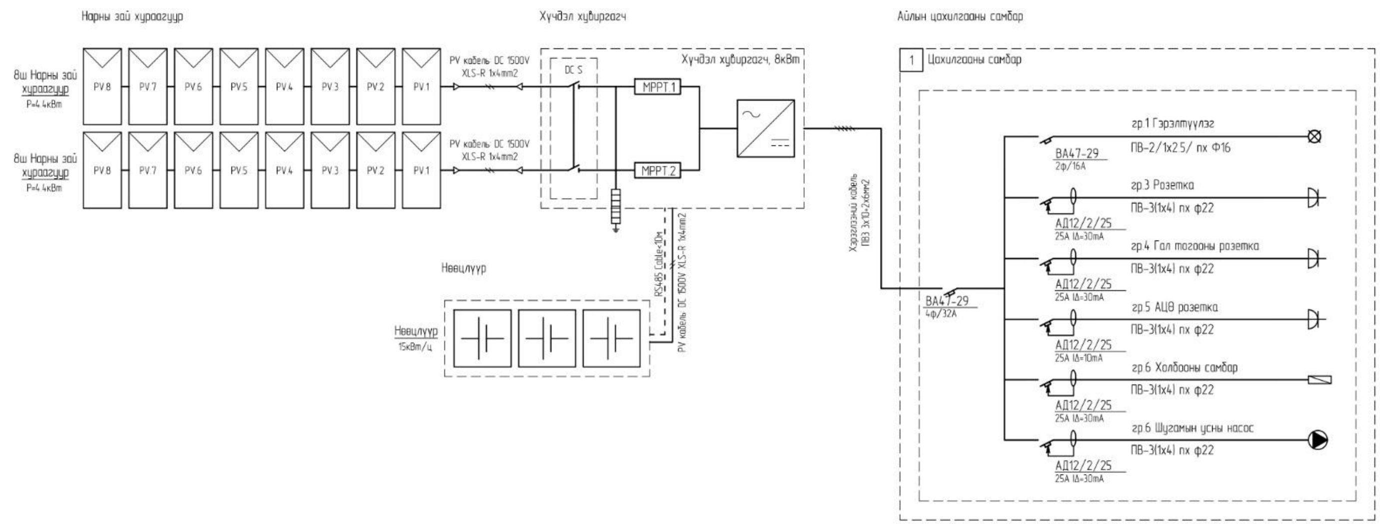
Хамгийн их чадал (Pmax)	550 Вт
Хүчдэл (В)	41.96 В
Гүйдэл (А)	13.11 А
Нээлттэй хэлхээний хүчдэл (В$_{dc}$)	49.92 В
Богино залгааны гүйдэл (А)	14 А
Модулийн ашигт үйлийн коэффициент	21.3 %
Хүлцэх алдаа	0 ~ +3 %
Модулийн материал, төрөл	Monocrystalline
Модулийн холболт	144 модуль (6 x 24)
Хэмжээ (У x Өр x Өн)	2,279 x 1,134 x 35 мм
Жин	28.6 кг
Холболтын хайрцаг (Хамгаалалтын зэрэг)	IP68
Нарны зай хураагуурын холбогч	MC4

Нөөцлүүрийн техник үзүүлэлт

Нөөцлүүрийн үзүүлэлт	
Нөөцлүүрийн хүчдэлийн хүрээ (В) /220В системд	350 – 600 В
Нөөцлүүрийн хүчдэлийн хүрээ (В) /380В системд	600 – 980 В
Нөөцлүүрийн багтаамж (кВт/ц)	15 кВт/ц
Хэт ачааллын гаралт (кВт)	7 кВт, 10сек
Цэнэглэх / цэнэг алдах чадал (кВт)	5 кВт
Нөөцлүүрийн төрөл	Lithium iron phosphate
Хэмжээ (У x Өр x Өн)	670 x 150 x 1320 мм
Жин	162 кг

Өвөрхангай аймаг, Бат-Өлзий сум АМИНЫ ОРОН СУУЦ					
Нарны зай хураагуурын ерөнхий үзүүлэлт					Үе шат A3
Инженер			ЕГ Шифр	Масштаб	Огноо 2023-05
Гүйцэтгэсэн		Т.Дашнамжил	ТГ Шифр	Зургийн дугаар XT-3	Бүх хуудас 7
Шалгасан					

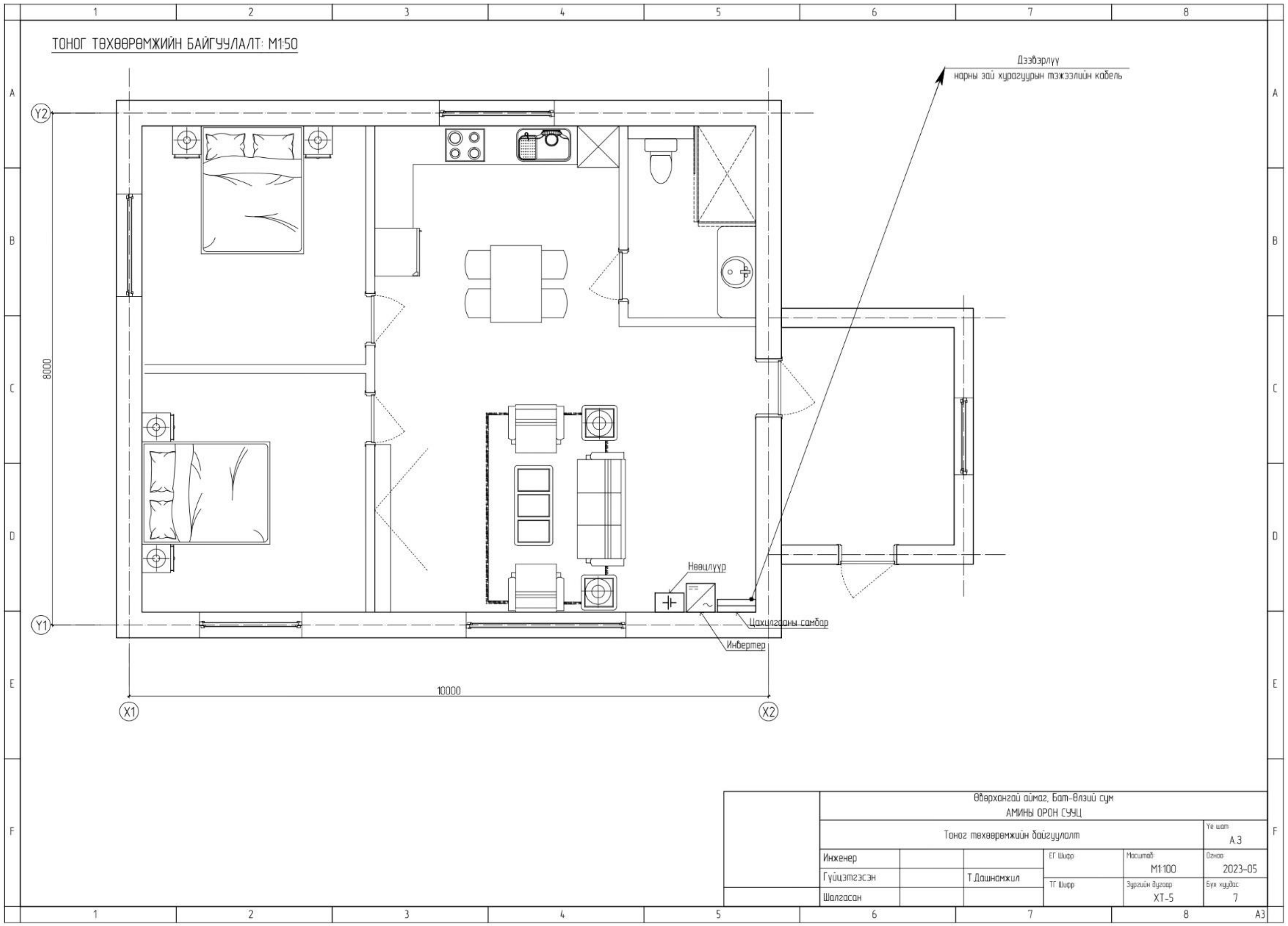
НАРНЫ ЦАХИЛГААН ҮҮСГҮҮРИЙН ХОЛБОЛТЫН БҮДҮҮВЧ

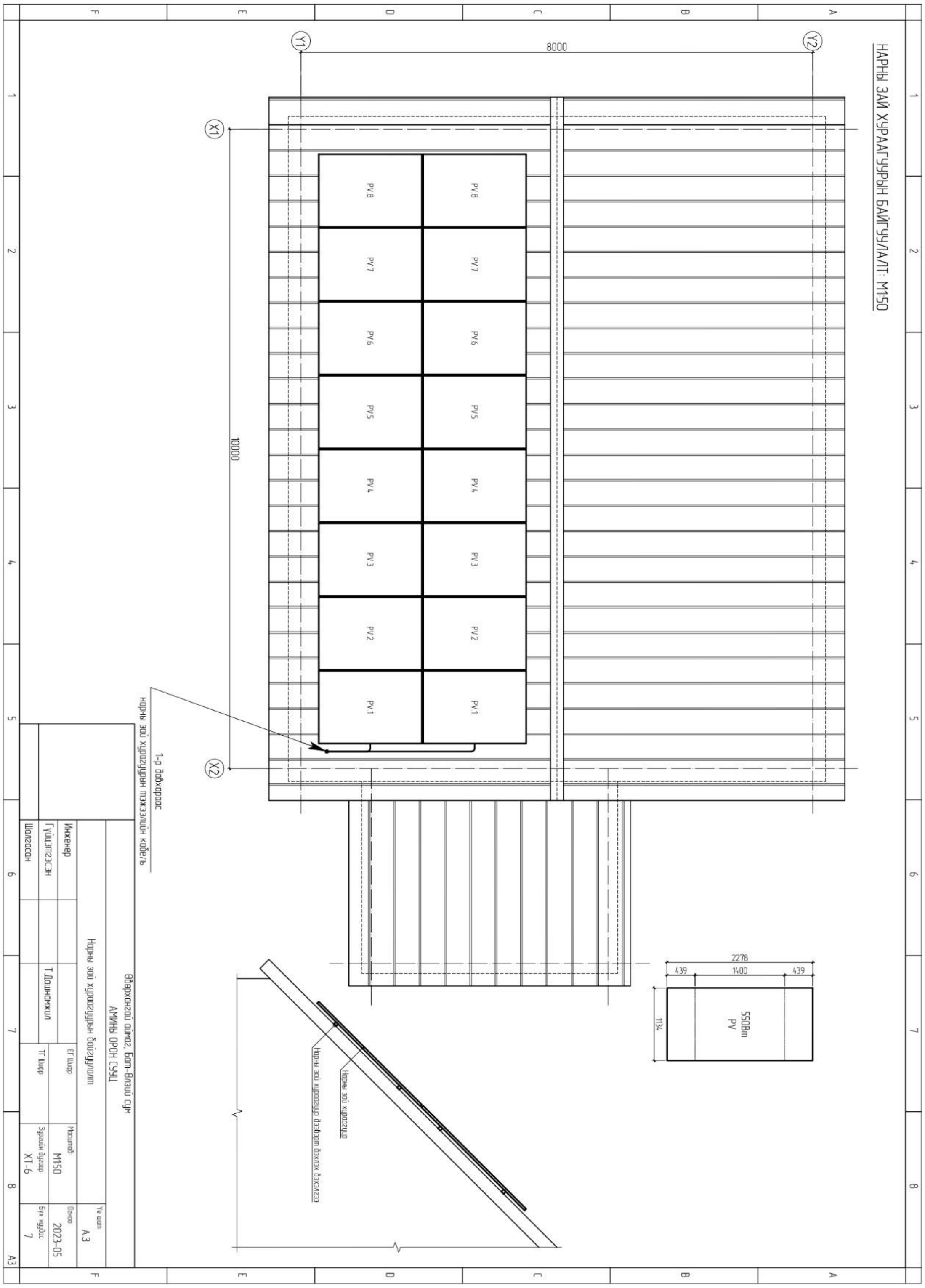


Өвөрхангай аймаг, Бат-Өлзий сум
АМИНЫ ОРОН СУУЦ

Нарны зай хураагуурын холболтын бүдүүвч

Инженер		ЕГ Шифр	Масштаб	Үе шат: А3
Гүйцэтгэсэн	Т.Дашнамжил			Огноо: 2023-05
Шалгасан		ТГ Шифр	Зургийн дугаар: ХТ-4	Бүх хуудас: 7


ТОНОГ ТӨХӨӨРӨМЖИЙН БАЙГУУЛАЛТ: М1:50
Дээврлүү
нарны зай хураагуурын тэжээлийн кабель
Нөөцлүүр
Цахилгааны самбар
Инвертер
8000
10000
Y1
Y2
X1
X2
Өвөрхангай аймаг, Бат-Өлзий сум
АМИНЫ ОРОН СУУЦ
Тоног төхөөрөмжийн байгуулалт
Үе шат
А.3
Инженер
Гүйцэтгэсэн
Т.Дашнамжил
Шалгасан
ЕГ Шифр
ТГ Шифр
Масштаб
М1:100
Огноо
2023-05
Зургийн дугаар
ХТ-5
Бүх хуудас
7



НАРНЫ ЗАЙ ХУРААГУУРЫН БАЙГУУЛАЛТ: M150
8000
10000
Y1
Y2
X1
X2
PV1
PV2
PV3
PV4
PV5
PV6
PV7
PV8
1-р давхраас
нарны зай хураагуурын тэжээлийн кабель
2278
439
1400
1134
550Вт
PV
Өвөрхангай аймаг, Бат-Өлзий сум
АМИНЫ ОРОН СУУЦ
Нарны зай хураагуурын байгууламж
Инженер
Гүйцэтгэсэн
Шалгасан
Т.Дашнямжил
Масштаб:
M150
Үе шат
А.3
Огноо
2023-05
Зургийн дугаар
ХТ-6
Бүх хуудас
7

ТАЙЛБАР БИЧИГ

Ерөнхий хэсэг

Энэхүү цахилгааны ажлын зургийг Барилга архитектурын зургийн даалгаврыг үндэслэн "Орон сууц олон нийтийн барилгын цахилгаан тоног төхөөрөмжийг төлөвлөх ба угсрах" барилгын дүрэм БД43-102-07, "Цахилгаан байгууламжийн дүрэм" БД43-101-03, "Байгалийн ба зохиомол гэрэлтүүлэг" БНбД23-02-08, "Барилга байгууламжийн аянга хамгаалалтын зураг төсөл зохиох заавар" барилгын дүрэм БД 43-103-08, "Цахилгаан техникийн ажил" БНбД3.05.06-90-ын дагуу хийж гүйцэтгэв.

Цахилгаан хангамж

Захиалагчийн хүсэлтийн дагуу 3 фазын 8кВт -ын чадал бүхий инвертер сонгосон. Энэ нь өдрийн (нартай байх үе) хэрэглээг бүрэн хангах ба 15кВт/ц нөөцлүүртэй бөгөөд шөнийн цагаар хэрэглээгээ бүрэн хангахаар тооцсон. Төвийн цахилгаан системд холбогдоогүй бие даасан систем юм.

Тоног төхөөрөмжийг угсрах

Нарны зай хураагуурыг цуваа холбох ба зориулалтын MC4 холбогч ашиглана. Нарны зай хураагуурын холболтыг зориулалтын галд тэсвэртэй, хэт ягаан туяа, тос, ус, үрэлтийн хамгаалалттай гадна зориулалтын кабелиар холбоно.

Дээврийн нарны зай хураагуураас инвертерлүү татагдах шугамд автомат таслуур мөн инвертерээс хэрэглэгчрүү татагдах шугамд автомат таслуур заавал тавих.

Цахилгааны кабелийг нарны зай хураагуурын рам хийцийн ард хар хоолойд сүвлэн татна.

Дээвэр дээр ил татах болон нарны зай хураагуурын суурь хооронд метал хоолойд сүвлэн татна.

Нарны зай хураагуурын суурь болон бүх метал хийцийг газардуулна.

Нарны зай хураагуурын суурь бэлдэх

Бетон суурио цутгахын өмнө анкер боолтыг зурагтай сайтар тулгаж үзэх.

Багана квадрат төмөрөө суурилуулсаны дараа бетон цутгах Явцад хөдөлгөхгүй байхыг хичээ.

Боолтны металын стандарт нь Q235 -ийн ган байх бөгөөд резбаг нь хамгаалхын тулд тос түрхэнэ.

Боолт бүр давхар гайк болон шайбатай байна.

Бүх метал эдлэлийг ус чийгний хамгаалалттай төмрийн будгаар будна. Будаг хийхийн өмнө метал хэсгүүдийг зэвийг зүлгэж, грунт тавьж өгнө.

Нарны зай хураагуурыг холбох чих болон босоо бэхэлгээ бүгд нарны зай хураагууртай хамт ирэх тул зурагт тусгаагүй болно.

Нарны зай хураагуурын суурийн бэхэлгээнд холбох нарны зай хураагуурын босоо бэхэлгээ төмрийн зузаан 4мм-с багагүй байна.

Зурагт тусгагдсан материалын түүвэр нэгж деталийн түүвэр болно.

ЗУРГИЙН БҮРДЭЛ

№	Зургийн нэр	Тайлбар
1	Тайлбар бичиг, Зургийн бүрдэл, Таних тэмдэг	ХТ-1
2	Материалын түүвэр	ХТ-2
3	Ерөнхий үзүүлэлт	ХТ-3
4	Нарны зай хураагуурын холболтын бүдүүвч	ХТ-4
5	Тоног төхөөрөмжийн байгуулалт	ХТ-5
6	Нарны зай хураагуурын байгуулалт	ХТ-6

ТАНИХ ТЭМДЭГ

№	Тэмдэглэгээ	Нэр	Хамгаалалтын зэрэг IP	Тайлбар
1		Гэрэлтүүлгийн самбар	IP-31	ГС
2		DC/AC инвертер		
3		Нарны зай хураагуур		
4		Электрон тоолуур, P		
5		Ердийн автомат таслуур, /MCB/		
6		Гүйдэл дамжуулах шугам		
7		Ган хоолой Ф22		
8		Цахилгаан дамжуулах утасны тоо		
9	N PE	Нойлын утас, хамгаалалтын утас		
10		Утас салбарлах хайрцаг		
11		Дамжуулагч, дээрээс доош, доороос дээш өнгөрөн гарахдаа уг байгуулалт дээрх хэвтээ тавигдах хэсэггүй зогсоорт шугам		
12	М, гр	Магистрал шугам, групп		
13	Pc, Pm, Im	Суурилагдсан чадал, Тооцооны чадал, Тооцооны гүйдэл		
14	Нэр Чадал	Нэр-Төхөөрөмжийн байгуулалт дээрх нэр, Чадал-Хөдөлгүүрийн чадал		
15				
16				

Өвөрхангай аймаг, Бат-Өлзий сум АМИНЫ ОРОН СУУЦ					
Тайлбар бичиг, Зургийн бүрдэл, Таних тэмдэг					Үе шат A 3
Инженер			ЕГ Шифр	Масштаб	Огноо 2023-05
Гүйцэтгэсэн		Т.Дашнамжил	ТГ Шифр	Зургийн дугаар ХТ-1	Бүх хуудас 7
Шалгасан					

Clean Resource Development

8кВт сүлжээнд холбогдсон, хосолсон системийн үнийн санал

ХЭРЭГЛЭГЧИЙН МЭДЭЭЛЭЛ		ҮНИЙН САНАЛЫН №	20230517-1
Хаана:	Дашнамжил	**ОГНОО**	5/17/2023
Холбоо барих хаяг:		**ХҮЧИНТЭЙ ХУГАЦАА**	5/31/2023
Холбоо барих утас:		**ХАНШИЙН МЭДЭЭ [USD]**	3500

БҮТЭЭГДЭХҮҮНИЙ НЭР	ЕРӨНХИЙ ҮЗҮҮЛЭЛТ	ТОО/Ш	НЭГЖИЙН ҮНЭ	НИЙТ ҮНЭ
Нарны зай хураагуур	550W BSM560M10-72HPH	16	760,000	12,160,000
Хүчдэл хувиргагч	Huawei SUN2000-8KTL-M1	1	4,300,000	4,300,000
Цэнэг хураагуур	Huawei Power Module LUNA2000-5KW-C0	1	3,510,000	3,510,000
	Huawei Battery Module LUNA2000 5kWh - E0, Li-ion	3	9,600,000	28,800,000
Цахилгааны хуваарилах систем	3 фазын цахилгааны хуваарилах систем	1	2,950,000	2,950,000
Бусад	MC4 холбогч гэх мэт нэмэлт материал	1	1,500,000	1,500,000
12 нарны зай хураагуурын суурь				4,000,000
Угсралт, туршилт тохируулга				4,000,000

* Үнийн саналын хүчинтэй хугацаа: 14 хоног	**Дүн [₮]**	**61,220,000**
* Төлбөрийн нөхцөл: Гэрээний дагуу	**НӨАТ [₮]**	**4,476,000**
* Хүргэлт: Улаанбаатар хотод хүргэлт үнэгүй.	**Нийт дүн [₮]**	**65,696,000**
* Улаанбаатар хотоос зайтай бол нэмэлт зардал гарна		

Үнийн санал боловсруулсан		Ц. Энхбаяр

Асуух зүйл байвал Ц.Энхбаяр, (+976) 99775789, enkhbayar@crd.mn хаягаар холбогдоно уу.

Reference

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2. ADB. Ulaanbaatar Air Quality Improvement Program: Report and Recommendation of the President. 2018; Available from: https://www.adb.org/projects/documents/mon-51199-001-rrp
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