



The present work was submitted to
the German-Mongolian Institute for Resources and Technology

IMPLEMENTATION OF MICROGRID AT GMIT CAMPUS

Bachelor's Thesis

By

MUNKHTUSHIG Amarsanaa

Study program: Electrical Engineer

Student ID: B2100398

1st Supervisor/Examiner: Ph.D.Nikita Abramov

2nd Supervisor/Examiner: Ph.D.Bold Enkhbold

Ulaanbaatar/Nalaikh

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Statutory Declaration

Amarsanaa Munkhtushig

Last name, First name

B2100398

Student ID number

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

IMPLEMENTATION OF MICROGRID AT GMIT CAMPUS

I did not use any sources other than those stated. In case the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Ulaanbaatar, Nalaikh, 06/05/2025

Place, Date

Signature

Abstract

This thesis presents the design, feasibility analysis, and implementation proposal of a hybrid microgrid system for the German-Mongolian Institute for Resources and Technology (GMIT) campus, integrating solar photovoltaic (PV), wind energy, and battery energy storage systems (BESS). The primary objective is to enhance energy security, reduce dependence on Mongolia's coal-dominated national grid, and offer a sustainable, cost-efficient, and educationally valuable energy solution. By assessing the campus's electricity demand—using 2023 and 2024 billing data—and aligning it with locally available renewable resources, the study proposes a technically feasible and economically viable microgrid architecture tailored to GMIT's needs. And because data is very limited, I simulated my data for consumption, wind energy, but used an official educational site for my PV systems generation at a certain location.

The proposed system includes a 200 kW PV array utilizing high-efficiency monocrystalline modules and a contract-based connection to the nearby Salkhit Wind Farm to access clean wind power. The total system pays itself from 5.652872-9.00485years but the system is expected to pay itself much faster, because the microgrid saves more money, the more energy our campus consumes. And also the typical payback cost for a microgrid with BESS is from 7 to 12 years. Supporting infrastructure costs—including inverters, mounting, wiring, transformers, and HVAC systems—are detailed, and life-cycle costs are projected over 20–25 years (with minimum 10 year warranty).

Acknowledgement

First and foremost, I would like to thank my thesis supervisors Prof. Nikita Abramov and Prof. Bold Enkhbold for their guidance, support, and invaluable insights throughout the research process. Their expertise and encouragement have been instrumental in shaping the direction of this study. They generously gave me their time and shared their experiences and perspectives. Without their valuable contributions, this research would not have been possible.

Furthermore, I would like to acknowledge the support of the faculty members of the GMIT and my friends for their constant encouragement, motivation. Finally, I would like to thank the faculty members of GMIT furthermore, for providing me with information, and data.

List of abbreviations

TWh= Terawatt hours

MWh= Megawatt hours

kWh= Kilowatt hours

PCC= Point of common coupling

DC= Direct current

AC= Alternating current

RES= Renewable energy sources

PV= Photovoltaic

BESS= Battery Energy Storage System

PPA= Power purchase management

TLCC= Total life cycle cost

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Chapter 1

Introduction and Literature Review

1.1 Introduction

Microgrids have become a viable method of integrating renewable energy sources while guaranteeing local energy security and efficiency as the demand for resilient and sustainable energy solutions rises globally. A microgrid is a small-scale energy system that can function both separately and in tandem with the larger power grid. In addition to energy storage devices, control systems, and intelligent monitoring technologies, it usually consists of a mix of renewable energy sources, including solar photovoltaic (PV) panels, wind turbines, and small-scale hydro systems.

In order to lower greenhouse gas emissions, lessen dependency on fossil fuels, and advance environmental sustainability, renewable energy is essential. Particularly, solar and wind energy have seen notable improvements in cost and efficiency, which makes them perfect for decentralized, remote energy systems like microgrids.

Communities, businesses, and for our purposes, institutions, can attain increased energy independence, cost savings, and environmental advantages by incorporating renewable energy sources into a thoughtfully managed microgrid. Additionally, by maintaining power supply during grid outages, microgrids provide greater resilience, which makes them particularly useful in isolated or rural locations with erratic grid connections.

1.2 Aim and purpose

The goal of this thesis is to develop and deploy a smart, dependable, and sustainable microgrid system on the GMIT campus that will increase energy independence, lessen its impact on the environment and give faculty and students a hands-on learning and research environment.

Objectives

1. Reliability and energy security

- Blackouts can be a significant setback for students, as we are aware because they can happen frequently on campus. During those blackouts, a microgrid offers dependability and energy security.
2. Use of Sustainable Energy
 - We require renewable energy sources to offset the growing load as the population grows.
 3. Educational worth
 - Give students studying electrical engineering, renewable energy, and control systems practical learning experiences. In addition to supporting research on energy management, smart grid technology, and system integration, our campus can serve as a model for other educational institutions, businesses, and homes.
 4. Cost efficiency
 - Optimize energy generation, storage, and consumption to reduce long-term energy costs.

1.3 Advantages and Disadvantages

By lowering dependency on the primary power grid, microgrids offer energy independence. By preserving the supply of electricity during grid outages, they improve reliability. They help to maintain a sustainable environment by promoting the use of renewable energy sources like wind and solar. Microgrids can eventually result in cost savings by managing energy effectively. They also provide worthwhile research and teaching opportunities, particularly in academic environments like the GMIT campus.

Because a microgrid requires specialized equipment and system design, the initial cost of implementation may be high. The technical complexity of microgrid operation necessitates the use of qualified staff for control and monitoring. Parts like batteries and inverters require routine maintenance. Furthermore, microgrids might not be able to handle sudden or extremely high energy demands due to their limited capacity.

However, these drawbacks can be overcome by having the microgrid pay for itself in the most economical manner possible, hiring professionals to train staff, allowing staff to handle routine maintenance, and having a large enough storage system to meet high demand.

1.4 Fundamental elements of microgrids

1.4.1 Power sources

These are the generators that provide power to the microgrid. Renewable energy sources include solar panels, wind turbines, and hydroelectric systems; non-renewable energy sources include diesel generators and natural gas.

1.4.2 Energy storage system

Excess power produced by the microgrid is stored in energy storage devices like flywheels or batteries. When demand outpaces supply or when power generation is sporadic (such as at night for solar power), this stored energy can be used.

1.4.3 Inverters, switchgear, and other devices

They enable the microgrid's control system to make adjustments to the microgrid's condition and link generation resources to consumers.

1.4.4 Smart metering

Smart meters are essential tools for collecting data on energy generation, consumption, and power quality characteristics in real time.

1.4.5 Point of common coupling (PCC)

This is the physical point where the microgrid connects to the main utility grid. In the event of a main grid outage, the microgrid can function in island mode by isolating it using the PCC.

1.5 Microgrid based on characteristics

1.5.1 Microgrid is a local system

This is a type of locally produced energy that is delivered to clients in the area. The large, centralized grids that have supplied the majority of our electricity for the past century are different from microgrids because of this. Central grids use transmission and distribution lines to transport electricity from power plants over great distances.

Since up to 8% to 15% of electricity dissipates during transit, power delivery from a distance is inefficient. By producing electricity close to the people it serves—the generators are located inside the building or nearby, or on the roof in the case of solar panels—a microgrid overcomes this inefficiency.

1.5.2 The microgrid is self-sufficient

Microgrids have the ability to function independently and cut off from the main grid. When a storm or other disaster results in a power grid outage, they can use this islanding capability to provide power to their customers. With over 5.7 million miles of transmission and distribution lines, the US central grid is particularly vulnerable to outages due to its vast size and interconnectedness.

Microgrids can function independently, but they rarely do (unless they are in a remote location with no central grid or a shaky one). Microgrids usually stay linked to the main grid instead. The two work together in a sort of symbiotic relationship when the central grid is functioning normally.

1.5.3 The microgrid is smart

Microgrids are intelligent, particularly sophisticated systems. This intelligence comes from the so-called microgrid controller, which is the system's brain and is responsible for highly sophisticated management of the generators, batteries, and adjacent building energy systems. To achieve the energy targets set by the microgrid's users, the controller coordinates a number of resources. They might be aiming for the best electric reliability, the lowest costs, the cleanest energy, or another goal. By varying the utilization of any of the microgrid's resources or combinations of them, the controller accomplishes these objectives. The controller, which is a software-based system, has numerous options for managing the energy supply. Here's an example, though. The central grid's power prices can be tracked in real time by an advanced controller. Instead of using energy from, say, its own solar panels, it might decide to purchase power from the central grid to serve its customers if energy prices are low at any given time. Instead, the microgrid's battery systems could be charged by its solar panels. The microgrid might discharge its batteries instead of using grid power later in the day when it gets pricey.

1.6 Different Microgrid Types

1.6.1 A remote microgrid

Because there is not any readily available or reasonably priced transmission or distribution (T&D) infrastructure in the area, off-grid microgrids are physically separated from the utility grid and always run in island mode.

Distributed energy resources (DER) from renewable sources, like solar and wind, usually offer these microgrids a more cost-effective and ecologically friendly way to run. In addition, a lot of remote microgrids are thinking about using battery energy storage systems instead of traditional generators for backup power.

1.6.2 Hybrid microgrid

Through a switching mechanism at the point of common coupling (PCC), these microgrids are physically connected to the utility grid; however, they can also disconnect into island mode and re-connect to the main grid as needed. In this instance, the utility service provider and the microgrid are successfully integrated to offer grid services (such as demand response, real and reactive power support, frequency and voltage regulation, etc.) to help address possible capacity, power quality and reliability, and voltage issues on the utility grid. In islanded mode, the microgrid needs local voltage and frequency controls, which can be supplied by a synchronous generator (such as a natural gas or fuel cell diesel generator) or energy storage (such as a battery or flywheel). Battery energy storage systems have been becoming more and more popular for microgrids that must function in both grid-connected and island modes because of their capacity to fulfill multiple tasks for grid services and emergency backup power. Grid-connected microgrids show economic viability for public safety, military bases, commercial buildings, industrial facilities, medical complexes, educational campuses, and agricultural farms when they serve a relatively small geographic area.

1.6.3 Networked microgrid

These kinds of microgrids cover a large geographic area and are made up of multiple distinct distributed energy resources (DERs) and/or microgrids linked to the same utility grid circuit segment. To operate and coordinate each grid-connected or island mode at

various tiers of hierarchy along the utility grid circuit segment, networked microgrids are usually optimized and managed by a supervisory control system.

Networked microgrids include community microgrids, smart cities, and new utility adaptive protection systems.

1.7 Microgrid topologies

Since they regulate the power flows of both generators and energy storage devices, inverters are the primary actuator in the control of AC microgrids. Generally speaking, inverters can be divided into three categories based on the control strategy: grid feeding, grid forming, and grid supporting. Different hardware topologies can be used to implement these inverters, and each has pros and cons.

1.7.1 AC microgrid

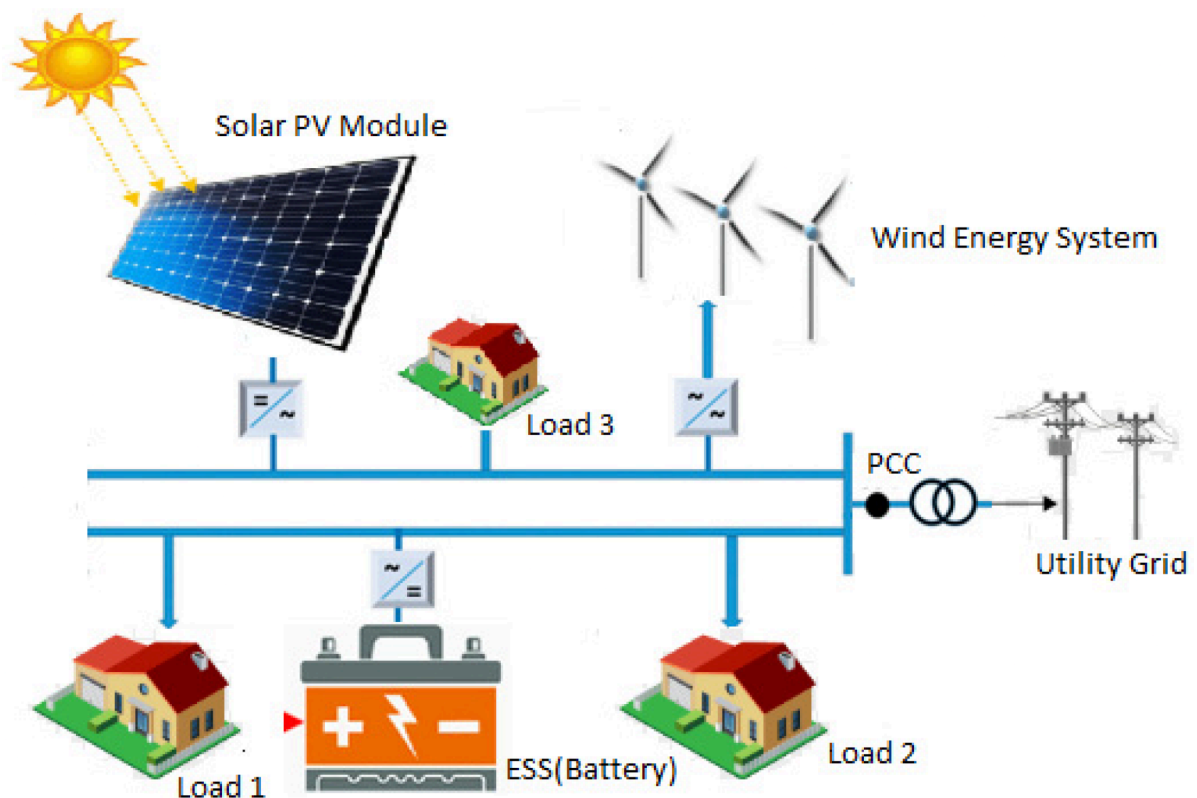


Fig1: Basic structure of an AC microgrid

Power sources with AC output are connected to the AC bus via the AC/AC converter, which changes the AC variable frequency and voltage into an AC waveform with a different frequency at a different voltage. On the other hand, power sources with DC output are connected to the AC bus via DC/AC converters.

1.7.2 DC microgrid

Power sources with DC output are either directly connected to the DC bus or connected via DC/DC converters in a DC microgrid topology. On the other hand, an AC/DC converter is used to connect power sources with AC output to the DC bus.

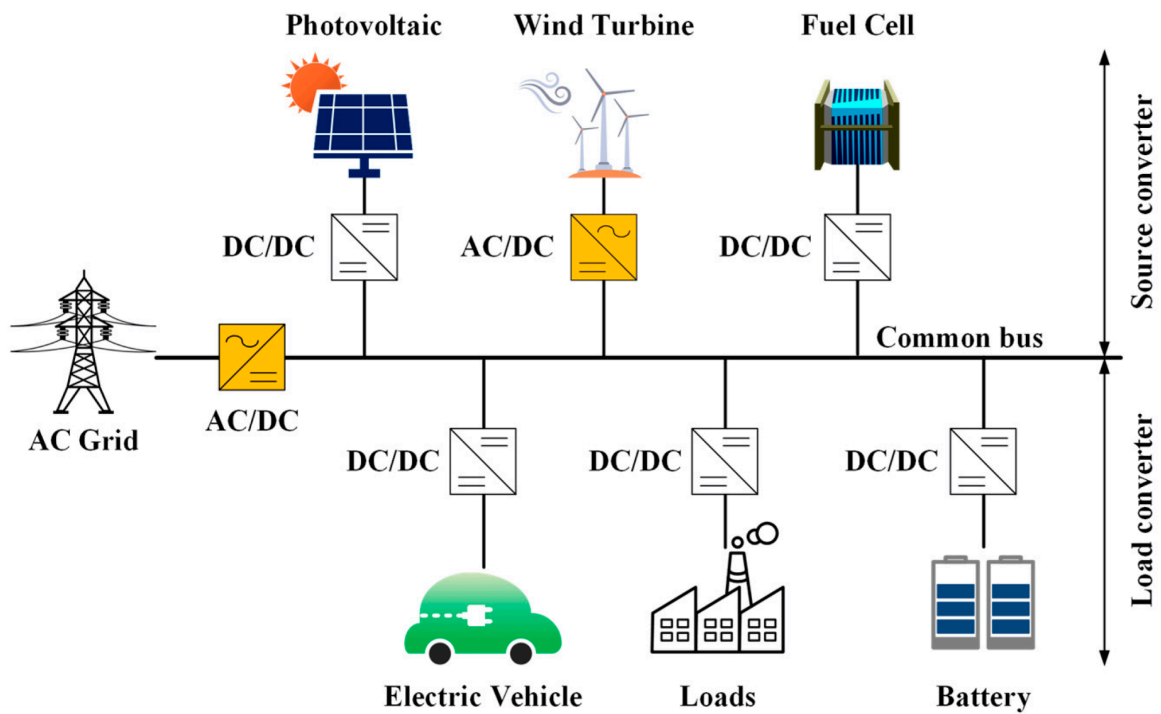


Fig2: Basic structure of an DC microgrid

1.7.3 Hybrid microgrid

Both AC and DC output power sources are supported by the hybrid microgrid's topology.

Additionally, a bidirectional converter connects the AC and DC buses, enabling power to move between them in both directions.

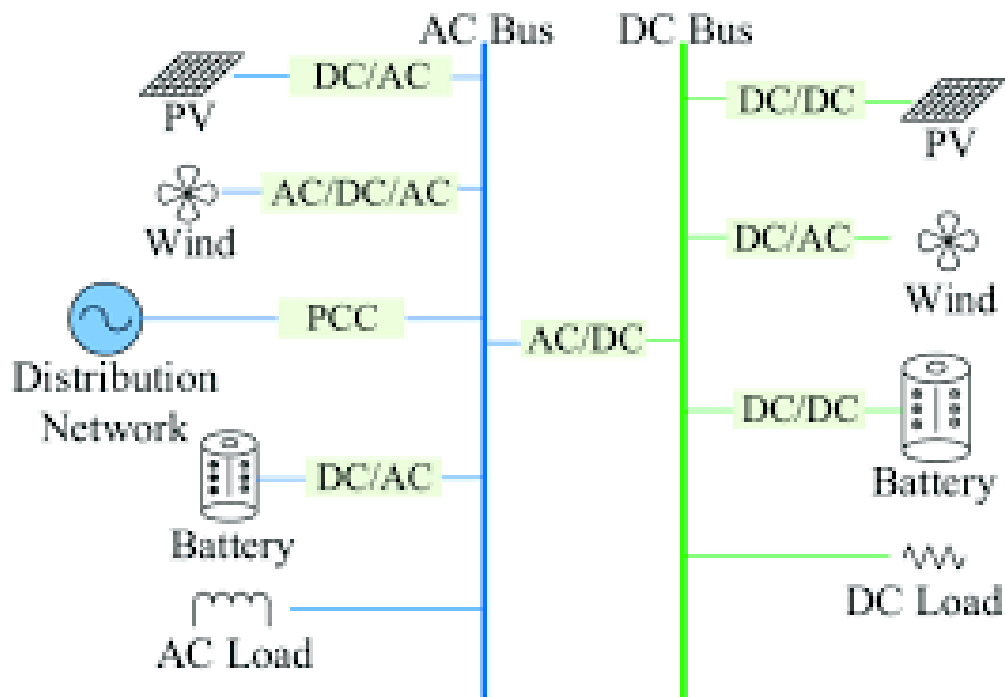


Fig3: Basic structure of an hybrid microgrid

1.8 Review of the Literature on RES

Energy from natural sources that replenish more quickly than they are used up is known as renewable energy. Examples of such sources that are continuously replenished are sunlight and wind.

1.8.1 Global RES data

Since the Industrial Revolution, fossil fuels have taken center stage in the energy mix of the majority of nations worldwide. Both human health and the global climate are significantly impacted by this. The burning of fossil fuels for energy is responsible for three-quarters of the world's greenhouse gas emissions. At least 5 million premature deaths occur each year as a result of local air pollution, which is mostly caused by fossil fuels.

In the upcoming decades, renewable energy will be crucial to decarbonizing our energy systems..Nowadays, renewable technologies provide about one-seventh of the world's primary energy.

The first chart on ourworldindata.org displays this as a stacked area chart, making it easier for us to see how the renewable mix is broken down and how much each contributes.

Hydropower is by far the most prevalent contemporary renewable energy source on a global scale. But we also observe that solar and wind power are expanding quickly.

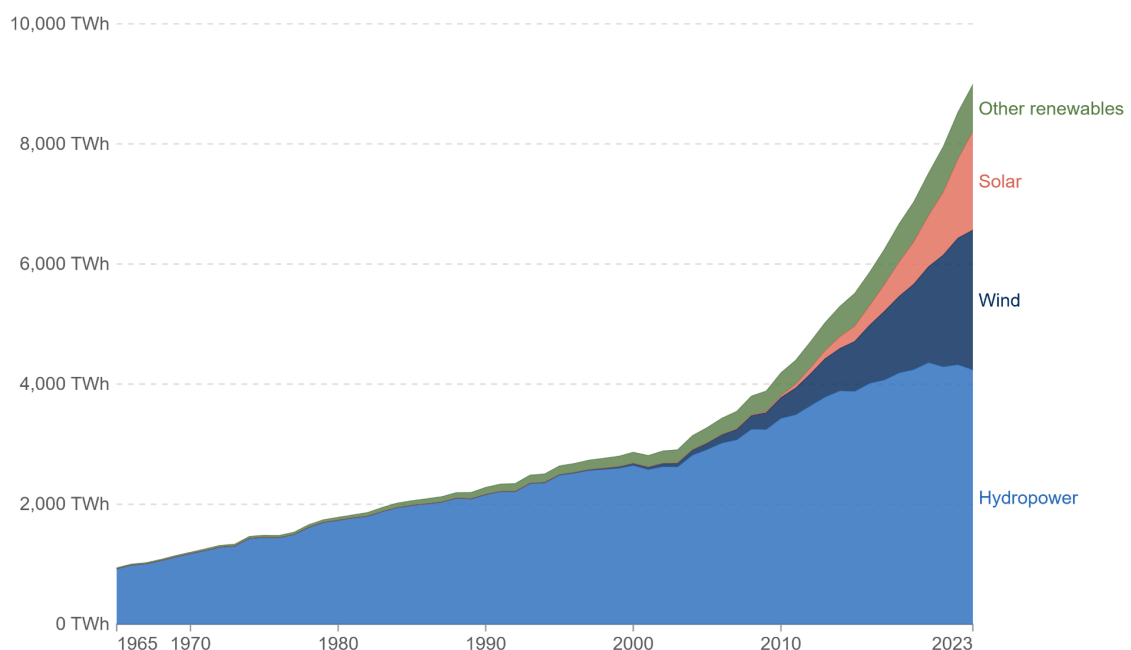


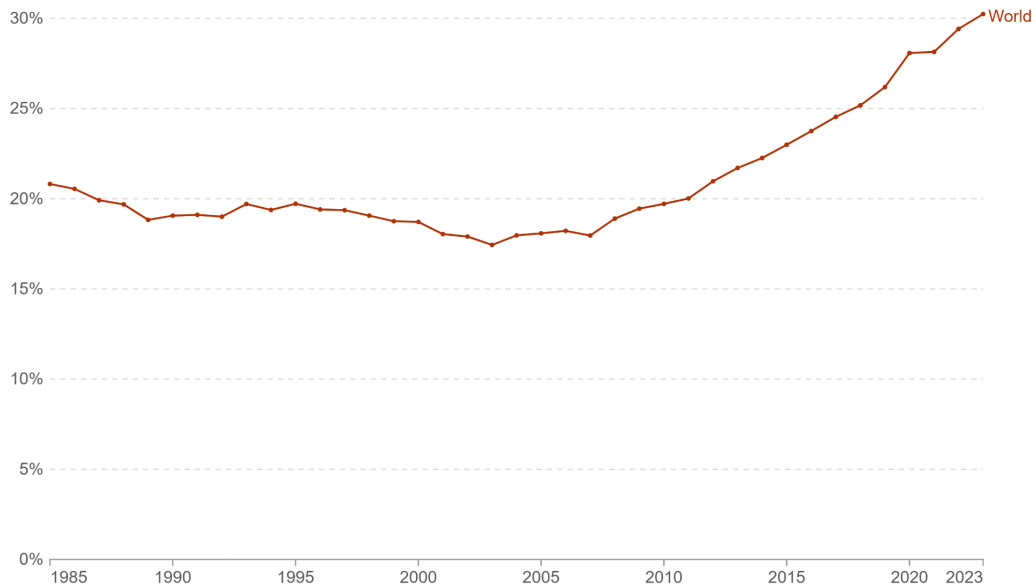
Fig4: The amount of energy production of every Renewable Energy Sources

Renewables typically make up a larger portion of the electricity mix than the overall energy mix because transportation and heating are more dependent on gas and oil and are therefore more difficult to decarbonize. An interactive chart displaying the percentage of electricity derived from renewable technologies can be found on the ourworldindata website. As you can see, renewable energy sources provide nearly one-third of the world's electricity. The energy's unit was measured in TWh.

Share of electricity production from renewables



Renewables include electricity production from hydropower, solar, wind, biomass & waste, geothermal, wave, and tidal sources.



Data source: Ember (2024); Energy Institute - Statistical Review of World Energy (2024)

OurWorldinData.org/energy | CC BY

Fig5: Renewable Energy Sources reaching 30% of the world's energy consumption in 2023

1.8.2 Solar energy

The process of turning solar energy into electrical power is how solar power operates. Heat and electricity are the two types of energy that the sun produces for human consumption. Both are produced using solar panels, which can be found on rooftops in homes or on "solar farms" that cover acres of rural land. Because solar panels last for more than 25 years, their carbon footprint is already fairly small. Additionally, the carbon footprint will continue to decrease because more and more of the materials used in the panels are recycled.

Silicon or another semiconductor material is typically used to make solar panels, which are then housed in a glass-encased metal panel frame. This substance releases electrons and generates an electric charge when exposed to photons, which are minuscule energy packets found in sunlight.

The wiring in solar panels absorbs the electric current produced by this PV charge. An inverter then transforms this DC electricity into AC. The electrical current used when plugging appliances into standard wall outlets is known as AC. The cleanest and most plentiful renewable energy source is solar energy, and Mongolia boasts some of the world's most abundant solar resources.

1.8.3 Wind energy

Kinetic energy, also known as the energy of motion, is the key to producing wind energy. At the very top of the turbine tower is a rotor that is connected to a set of propeller blades in each wind turbine. A nacelle, which resembles a box and houses a generator and shaft, is attached to the rotor. A series of churning processes convert the kinetic energy into electrical energy: the wind rotates the blades, which in turn rotates the rotor, which in turn rotates the shaft, which in turn rotates the generator. The generator's electricity travels through a transformer after passing through the turbine tower, where it is transformed into the appropriate voltage before being sent to our power grid. Wind turbines can generate more energy the larger they are. Because wind blows more steadily and encounters less resistance at higher altitudes, turbines are also tall.

1.9 Current state of Mongolia

About 90% of the electricity generated in 2023 will come from coal, making it the dominant energy source. Among them are thermal power plants like

Ukhaa Khudag, Erdenet, Amgalan, Buuruljuut, Ulaanbaatar TPP-2, 3 and 4, Darkhan, Choibalsan, and Dalanzadgad. In order to meet Ulaanbaatar's increasing energy needs, a second 300MW coal-fired thermal power plant is being built.

In 2023, renewable energy sources accounted for about 9.6% of all electricity produced. The following lists cover the various kinds of RES:

The following are major solar power plants:

Name	Capacity	Location	Commissioned	Annual Generation
Gobi Solar Power Plant	30 MW	Sainshand, Dornogovi	2020	56.8GWh

Gegeen Solar Plant	15 MW	Zamiin Uud, Dornogovi	2018	29.6GWh
Bukhug Solar Plant	15 MW	Sergelen, Töv	2019	29GWh
Darkhan Solar Plant	10 MW	Khongor, Darkhan-Uul	2017	15.2GWh
Monnaran Solar Plant	10 MW	Ulaanbaatar	2017	20GWh
Sumber Solar Plant	10 MW	Sumber, Gobisumber	2019	17.1
Khovd Nar Solar Plant	10 MW	Myangad, Khovd	2022	22GWh
Murun Solar Power Plant	10 MW	Mörön, Khövsgöl	2023	15.5GWh

Table1: Major solar power plants in Mongolia

Major Wind farms are:

Name	Capacity	Location	Commissioned	Annual Generation
Sainshand Wind Farm	55 MW	Sainshand, Dornogovi	2018	210GWh
Tsetsii Wind Farm	50 MW	Tsogttsetsii, Umnugovi	2017	183GWh
Salkhit Wind Farm	49.6MW	Sergelen, Töv	2013	170GWh

Table2: Major Wind farms in Mongolia

The Durgunii Hydro Plant, Taishir Guulin Plant, and Bogdiin Gol Plant, which have a combined capacity of 25MW, are additional noteworthy hydropower projects.

Additionally, in 2023, about 22% of electricity was imported from nearby nations like China and Russia.

As of April 2025, Mongolia has made great progress in integrating large-scale BESS to improve grid stability, support the integration of renewable energy, and lessen dependency on energy imports in order to meet Ulaanbaatar's growing energy demand. The following are Mongolia's most noteworthy energy storage initiatives:

- This 50MW/200MWh battery storage power station, which is situated in the Baganaur district, was put into service on December 6, 2024. Supplies electricity to approximately 25,000 households. It stores energy during low-demand periods and discharges during peak times, aiding in frequency regulation and reducing winter load stress on the central grid.
- Located in Uliastai, Zavkhan Province, the 3.6 MW Tseengeg Battery Storage Power Station was put into service in 2022. It was the first utility-scale solar-plus-storage project in Mongolia, lowering reliance on imported energy and delivering dependable electricity to isolated regions.

Chapter 2

Methodology

Clearly defining the project's goals and parameters is the first step in constructing a microgrid on the GMIT University campus using solar photovoltaic (PV) and wind energy. Enhancing campus energy security, lowering reliance on outside power sources, incorporating renewable energy into the classroom, and showcasing sustainable practices in accordance with Mongolia's renewable energy targets would be the main objectives.

The next phase involves conducting a detailed energy demand assessment of the campus. This includes analyzing historical electricity consumption data (if available) or estimating it based on the number of buildings, usage patterns, occupancy rates, and equipment load profiles. Seasonal variations should be considered, especially given Mongolia's extreme winter conditions and different academic term loads. Based on this demand profile, the system size for PV arrays and wind turbines can be roughly estimated. Following demand analysis, a comprehensive resource assessment must be conducted. Solar irradiation data and wind speed data specific to the GMIT campus area must be gathered.

Once resource availability is confirmed, the system design phase can begin. This involves sizing the PV system and wind turbines to match the campus's load profile while considering efficiency losses. Battery energy storage systems should also be sized to store excess energy and provide backup during periods of low generation. A control system must be designed to manage energy flow between the PV, wind, batteries, and the campus loads, with smart inverters, controllers, and possibly a campus-level energy management system (EMS).

Chapter 3

Data acquisition

3.1 Transcript of electric bill of 2023, and 2024

This is our school's detailed transaction report from the beginning of 2023 till the end of 2024. This data shows recorded electricity meter readings, the amount of energy used[kWh], the amount of loss from transformers[kWh], demand tariff[kWh], and the amount of money they cost in mnt. These values that I mentioned are the most important part of this transcript(unlike other costs like cleaning or other labor costs that were on the transcript).

And here are the meanings:

-Хэрэглээ[КВц]= Consumed electrical energy[kWh];

-Хоосон явалт[КВц]= Transformer loss[kWh];

-Чадлын тариф[КВц]= Demand tariff[kWh];

-Нийт[КВц]= Combined energy consumption[kWh];

-Мөнгөн дүн[төг]= Cost due to consumed electrical energy[mnt];

-Хоосон явалт[төг]= Cost due to transformer loss[mnt];

-НӨАТ[төг]= VAT[mnt];

-Чадлын тариф[төг]= Cost due to demand tariff[mnt];

-Дүн[төг]= Combined cost[mnt]

Хэрэглэгчийн давсны дэлгэрэнгүй тайлан

Хэрэглэгчийн код: 7119440
 Нэр: МОНГОЛ ГЕРМАНЫ ХАМТАРСАН ТЕХНОЛОГИЙН ДЭЭ
 Борлуулалтын шилт: R4
 Регистр: 5783224
 Дэд станиц: ХТП-07104,ХТП-07104
 Хаяг: НД-2Х А.Ш эмнэлгийн Т-баруун талд
 Эхний үлдэгдэл: 5.84
 Хамрах хугацаа: 2023.01.01 - 2025.02.20
 Хэвлэсэн огноо: 2025.02.20

Огноо	Гүйлгээ	Тоолуурын дугаар	Бичигт		Хэрэглээ кВт.ц	Мөнгөн дүн /төг/	Орлого Мөнгөн дүн /төг/	
			Тоолуурын звалт					
			Өмнөх	Одоо				
2023.01.01	Тариф 1 (Энгийн)	18130876	403.00	404.86	381.30	62,678.09		
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	ТВ -ийн хураамж	03				1,650.00		
НӨАТ(үйлч)					30.00			
Дүн					51,526.76	10,671,185.06	0.00	
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	Энгийн тарифаар	18130892		19.00	163.67	1,679,244.00		
	НӨАТ					1,477,417.40		
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	Дүн					62,065.72	16,251,591.78	0.00
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Дүн						0.00	26,922,783.00	
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	Хоосон явалт	18130876			543.66	114,598.09		
	Чадлын тарифаар	18130892		28.00	252.59	2,909,836.80		
	Чадлын тарифаар	18130876		28.00	1.83	21,081.60		
	НӨАТ					2,118,229.28		
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	Тариф 1 /хуурмаг/	18130892	1,538.00	1,576.00	7,790.00			
	Мэд.Хүр.төлбөр	03				300.00		
	ТВ -ийн хураамж	03				1,650.00		
	НӨАТ(үйлч)					30.00		

Fig6. Transcript of electric bill of 2023, and 2024

3.1.1 Conversion to monthly data

These two tables below were converted from the transcript of the electrical bill of 2023, and 2024. The transcript consisted of 32, 29, 25, 24, and even 1 day of data which was hard read, so the values were averaged into monthly data.

2023	Хэрэглээ кВт.ц	Хоосон явалт	Чадлын тарифа: Нийт кВт.ц	Мөнгөн дүн төг	Хоосон явалт	НӨАТ	Чадлын тарифа: Дүн
Jan	94,860.30	1,174.40	264.8	96,299.50	20,005,465.70	247,550.00	2,309,578
Feb	72,170.26	1,135.69	209.23	73,515.18	15,234,526.73	277,701.33	1,788,425
March	53626.05	1216.14319	147.76	54989.95319	11303839.77	175220.2436	1,702,669
April	47,932.21	1,217.45	134.75	49,284.41	10,103,639.33	256,629.99	1,553,109.26
May	32,306.72	1,211.13	86.055	33,603.90	6,809,933.24	255,293.15	805,668.43
June	19,667.19	1,197.69	51.218	20,916.10	4,145,646.16	252,330.46	502,936.88
July	13,614.37	1,241.48	36.64	14,892.49	2,869,775.47	261,403.54	364,477.36
August	17,318.96	1,188.32	42.661	18,549.94	3,650,663.80	250,488.28	387,119.52
Sep	21,066.55	1,133.99	40.36	22,240.90	4,440,618.61	239,036.31	366,245.43
Oct	28,112.23	1,336.47	64.32	29,513.02	5,925,777.68	281,715.57	592,406.63
Nov	46,838.50	1,228.14	80.951	48,147.59	6,347,686.44	258,879.20	753,912.95
Dec	48,912.08	1,410.17	114.495	50,436.75	9,176,964.55	15,091.20	1,078,147.71

Fig7: Monthly power consumption data of 2023

2024	Хэрэглээ кВт.ц	Хоосон явалт	Чадлын тарифа: Нийт кВт.ц	Мөнгөн дүн төг	Хоосон явалт	НӨАТ	Чадлын тарифа: Дүн
Jan	48,862.18	2,178.31	115.1	51155.59	10,299,659.94	459,166.53	1,208,482
Feb	45,851.91	1,624.72	125.1	47,601.73	9,001,390.30	342,476.26	1,144,886
March	47,280.40	1,821	142.15	49,243.53	7,649,909.08	383,844.50	1,198,780.03
April	37,680.31	1,723.43	101.29	39,505.03	7,942,635.18	363,282.19	947,280.79
May	32,000.83	1,789.32	84.34	33,874.49	6,745,457.20	377,173.29	809,428.58
June	19,154.75	1,726.96	49.5	20,931.21	4,037,630.68	364,028.36	497,199.65
July	15,123.72	1,766.91	41.04	16,931.67	3,187,931.12	372,448.87	403,299.67
August	24,765.65	1,783.82	67.87	26,617.34	5,220,352.74	375,519.57	637,790.68
Sep	33,094.03	1,698.45	76	34,868.48	6,975,892.76	357,999.62	842,832.47
Oct	46,171.80	1,680.87	132.03	47,984.70	9,732,556.14	354,311.15	1,160,793.17
Nov	54,713.03	1,735.20	168.605	56,616.84	13,087,994.41	412,990.55	1,580,611.15
Dec	64,251.31	7741.6	166.41	64,417.72	17,026,599	196524	1,980,262.04

Fig8: Monthly power consumption data of 2024

Conversion of 2023, and 2024 transcript to monthly data

The amount of energy consumption each month [KWh]

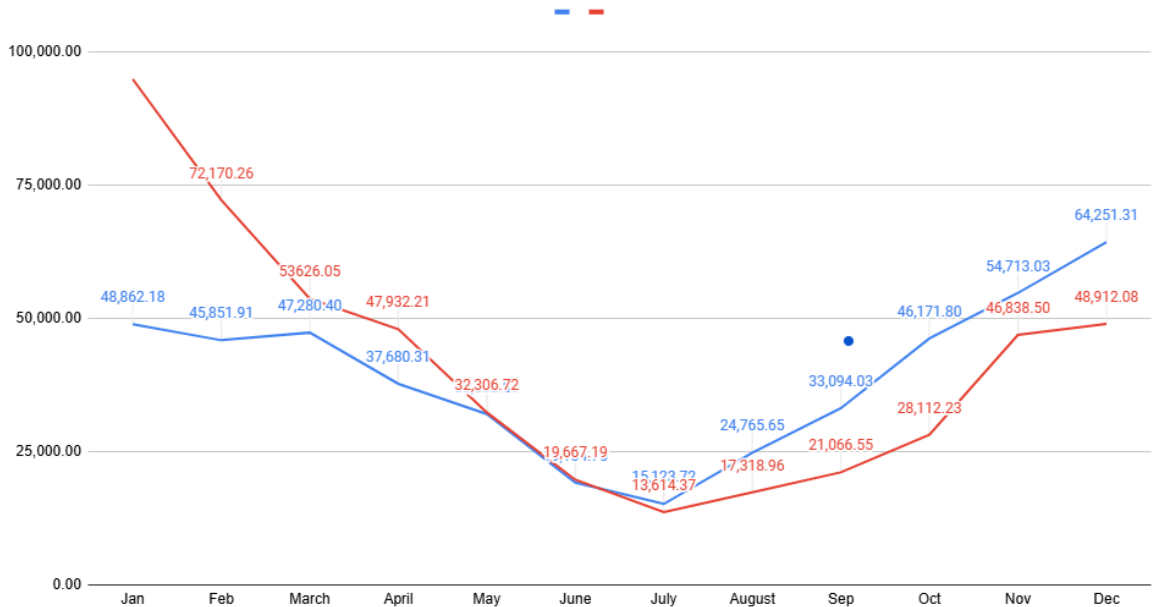


Fig9: Energy consumption in each month in KWh

Conversion of 2023, and 2024 transcript to monthly data
The amount of payment in each month[mnt]

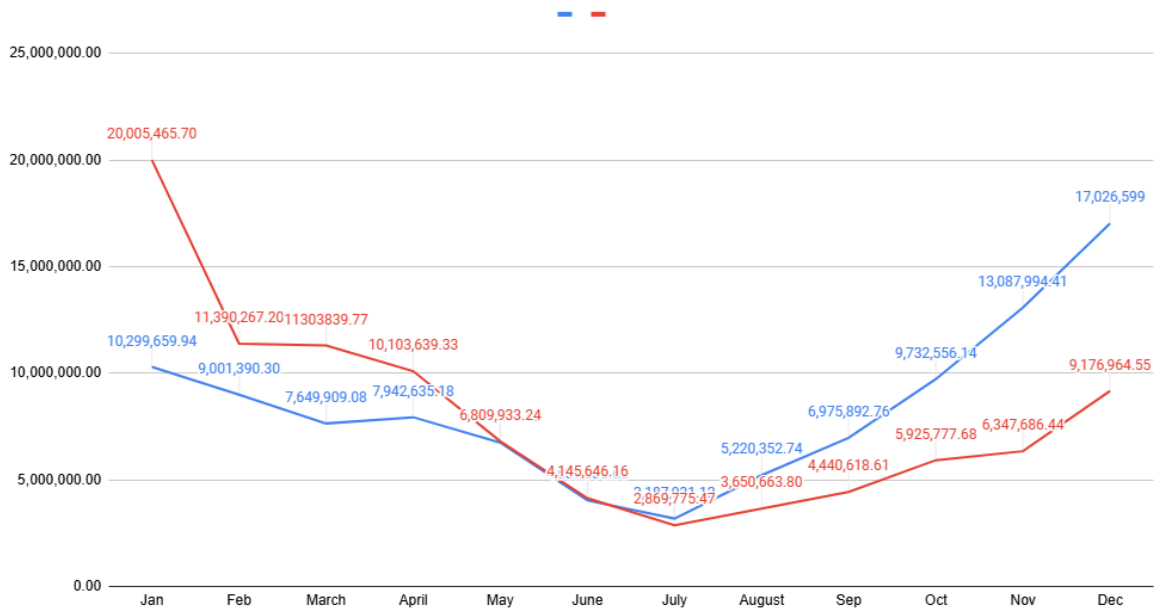


Fig10:Payment for only energy consumption in mnt

As you may see from these two graphs above are very similar, because the cost graph is found by using the data of energy consumption. But you may see a slight difference at the end of 2023, specifically the month November and December. It's not at all true that the consumption graph, and cost graph should be exactly the same. This is due to our school's tariff being calculated in 3 tariff metering systems, which this difference in graph is because of a large amount of energy being used in different tariff hours (most probably, during the colder seasons, students using heater for their rooms during the peak demand hours and raising the cost curve).

3.1.2 Tariff system

A tariff is a tax imposed by one country on the goods and services imported from another country to influence it, raise revenues, or protect competitive advantages. The rate at which electrical energy is supplied to a consumer is known as tariff. Cost of Producing Electricity depends upon the magnitude of Electricity consumed by the load. The tariff values mentioned above are calculated as follows:

- **Consumed electrical energy[Kwh]** which is measured in 3 tariff metering system

Mid-load (or normal) hours (06:00-17:00) – moderately priced.(285mnt/kWh);

Peak hours (17:00-22:00)– when electricity is most expensive.(476mnt/kWh);

Off-peak hours (22:00-06:00)– when electricity is cheapest.(160mnt/kWh);

№	Ангилал	Хэмжих нэгж	Тариф
1	Уул уурхайн олборлох, боловсруулах аж үйлдвэр, зарим аж ахуйн нэгж, байгууллага <i>Үүнд:Нүүрс олборлолт, боловсруулалт Газрын тос, шатдаг хий олборлолт, боловсруулалт Төмрийн хүдэр олборлолт, боловсруулалт Түгээмэл тархацтай ашигт малтмал олборлолт Бусад ашигт малтмал олборлолт, боловсруулалт Банк, банкны нэгж Согтууруулах ундаа үйлдвэрлэх тусгай зөвшөөрөл эзэмшигч Криптовалют олборлох, үйлдвэрлэх үйл ажиллагаа эрхлэгч</i>		
1.1	Энгийн тоолууртай	төг/кВт.ц	285.00
1.2	3 тарифт тоолууртай		
а	Өдрийн хэрэглээ /06.00 цагаас 17.00 цаг хүртэл/	төг/кВт.ц	285.00
б	Оройн хэрэглээ /17.00 цагаас 22.00 цаг хүртэл/	төг/кВт.ц	476.00
в	Шөнийн хэрэглээ /22.00 цагаас 06.00 цаг хүртэл/	төг/кВт.ц	160.00
2	Үүрэн холбооны үйлчилгээ эрхлэх тусгай зөвшөөрөл эзэмшигч		
2.1	Энгийн тоолууртай	төг/кВт.ц	275.00
2.2	3 тарифт тоолууртай		
а	Өдрийн хэрэглээ /06.00 цагаас 17.00 цаг хүртэл/	төг/кВт.ц	275.00
б	Оройн хэрэглээ /17.00 цагаас 22.00 цаг хүртэл/	төг/кВт.ц	437.00
в	Шөнийн хэрэглээ /22.00 цагаас 06.00 цаг хүртэл/	төг/кВт.ц	160.00
3	Бусад үйлдвэр, аж ахуйн нэгж, байгууллага		
3.1	Энгийн тоолууртай	төг/кВт.ц	265.00
3.2	3 тарифт тоолууртай		
а	Өдрийн хэрэглээ /06.00 цагаас 17.00 цаг хүртэл/	төг/кВт.ц	265.00
б	Оройн хэрэглээ /17.00 цагаас 22.00 цаг хүртэл/	төг/кВт.ц	397.00
в	Шөнийн хэрэглээ /22.00 цагаас 06.00 цаг хүртэл/	төг/кВт.ц	160.00

Fig11:tariff system

And when calculating the consumption cost of the given day(let's say which is D), we will follow this equation as follows:

A=The amount of energy consumed during Mid-load[kWh];

B=The amount of energy consumed during Peak hours[kWh];

C=The amount of energy consumed during Off-peak hours[kWh];

$$A*285\text{mnt/KWh}+B*476\text{mnt/KWh}+C*160\text{mnt/KWh}=D$$

- **Transformer loss[Kwh]**

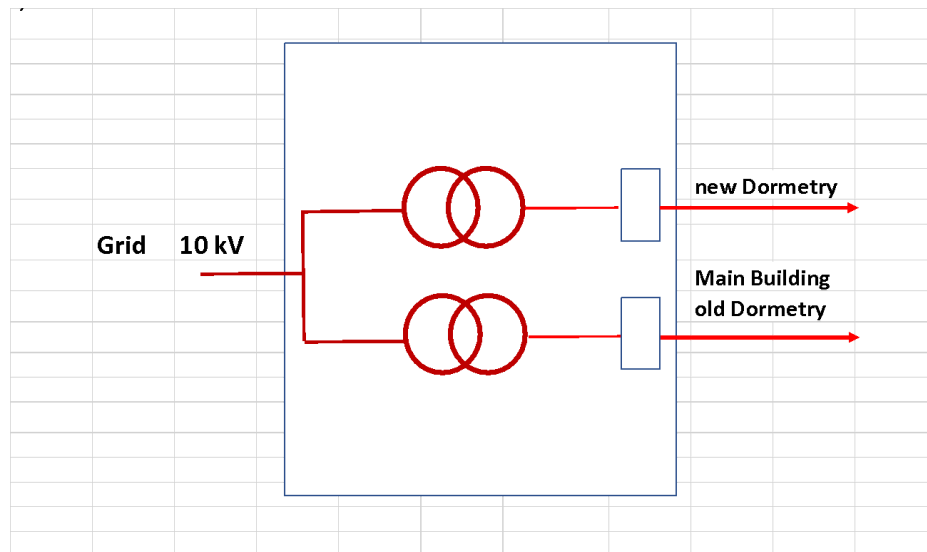


Fig12:Transformer configuration to the campus

These are constant losses that occur whenever the transformer is energized, regardless of the load. Formula being:

$$\text{No-load Loss} = P[\text{core}]$$

Which P_{core} is usually provided by the manufacturer (in watts or kilowatts).

$$\text{Load Loss} = P[\text{cu_rated}] * (S([\text{load}]/S[\text{rated}]])$$

Or

$$\text{Load loss} = P[\text{cu_rated}] * (I([\text{load}]/I[\text{rated}]))^2$$

$P[\text{cu_rated}]$ = copper loss at rated load (given by the manufacturer);

$S[\text{load}]$ = actual load in kVA;

$S[\text{rated}]$ = rated kVA of the transformer;

And total loss would be: Total Loss=No-load Loss+Load Loss

And at the end, you would simply multiply this total loss to the tariff(mnt/kWh).

But I believe given the data for transformer loss, the substation of Nalaikh district would count both of our transformers working for 24 hours the whole day for the whole month,

and that would explain why they would write us a similar bill of the transformer loss each month.

- **Demand tariff cost**

Demand tariff is different from the regular energy tariff, which charges you based on the total amount of electricity consumed over time. The demand tariff reflects the capacity you require from the substation—essentially, the size of the electrical "pipeline" you need to support your peak usage.

Utilities monitor your electricity usage during specific peak demand hours, such as between 5:00 PM and 10:00 PM. During this time, your highest usage (the most energy consumed at once) is recorded. The demand charge is then calculated by multiplying this peak demand by a set rate called the demand tariff

$$T[\text{power charge}] = P[\text{avg,month}] * T[\text{power tariff}], \text{ in mnt};$$

$$P[\text{avg,month}] = \sum P[\text{max,day}] / t[\text{days in month}], \text{ kW};$$

$$T[\text{power charge}] = \text{Power charge(mnt)};$$

$$T[\text{power tariff}] = \text{Power tariff(mnt/kW/month)};$$

$P[\text{avg,month}]$ = The user's monthly average of the maximum power demand during peak load hours (17:00–22:00) (in kW);

$P[\text{max,day}]$ = The highest power demand used during the peak hours (17:00–22:00) for each calendar day of the month (in kW);

$t[\text{days in that month}]$ = Number of calendar days in the month.

3.2 Feasibility study of RES at Nalaikh

3.2.1 Solar energy feasibility

The area around Nalaikh is shown as an area with high irradiation. So, the use of solar energy for energy has a high potential.

DIRECT NORMAL IRRADIATION
MONGOLIA

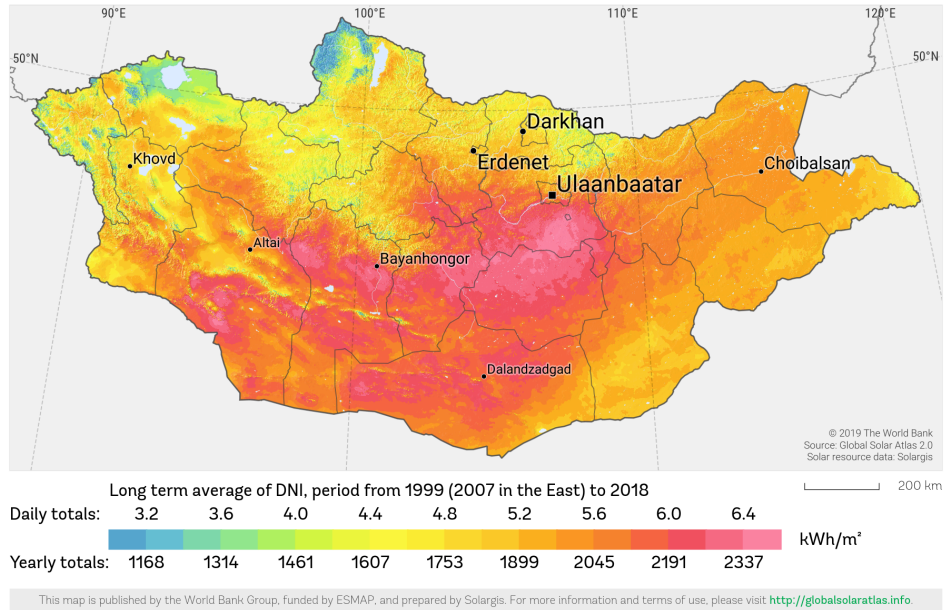


Fig13: Average of direct normal Irradiation

3.2.2 Wind energy feasibility

From globalwindatlas.info, we see that Nalaikh doesn't have as much wind speed compared to the mountains. The wind speed was measured in m/s. Unless we are building this energy source on a larger scale and on the mountains, harnessing wind energy is difficult and harder to do maintenance than solar panels.

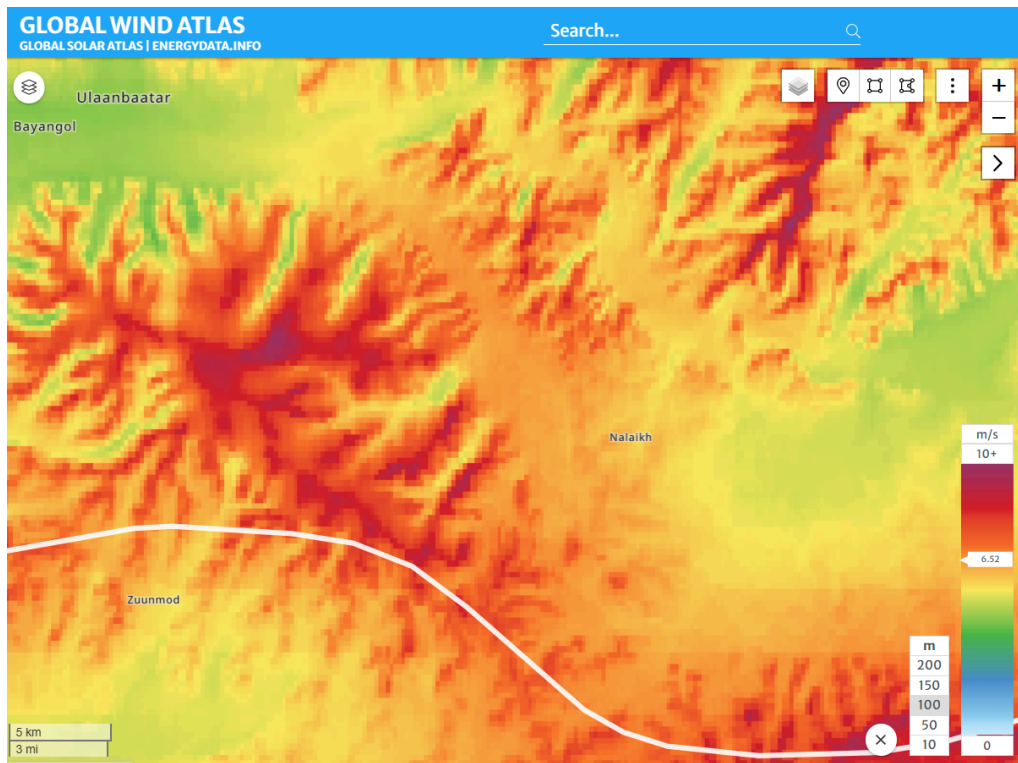


Fig14: Mean wind speed from Global Wind Atlas, around Nalaikh district

3.3 Energy consumption distribution dataset

Our university has a lack of data record when it comes to consumption distribution. The only valid data I worked with was the transcript above.

And when there is a lack of data, there are always opportunities to improve. But in my case I used a 12 month data of hourly consumption level for a commercial-type building, to distribute my monthly consumption data. This way we can visualize how the generation would meet our university's load.

3.3.1 Example dataset

Choosing a dataset in my case, could be from any year. I just need the average consumption distribution and transform my monthly data as the same as my chosen dataset. I chose from Mendeley data, a 12 month data of hourly consumption level for a commercial-type building from 2016 that has 8784 recorded data with hourly distribution and consumption size.

This was the following data:

	A	B	C	D	E	M
1	consumption	hour_of_day	day_of_week	day_of_month	month_of_year	
2	0.255	1	5	1	1	
3	0.264	2	5	1	1	
4	0.253	3	5	1	1	
5	0.25	4	5	1	1	
6	0.234	5	5	1	1	
7	0.249	6	5	1	1	
8	0.297	7	5	1	1	
9	0.323	8	5	1	1	
10	0.423	9	5	1	1	
11	0.418	10	5	1	1	
12	0.418	11	5	1	1	
13	0.431	12	5	1	1	
14	0.424	13	5	1	1	
15	0.424	14	5	1	1	
16	0.426	15	5	1	1	
17	0.419	16	5	1	1	
18	0.423	17	5	1	1	
19	0.434	18	5	1	1	
20	0.393	19	5	1	1	
21	0.367	20	5	1	1	
22	0.356	21	5	1	1	
23	0.313	22	5	1	1	
24	0.288	23	5	1	1	
25	0.284	24	5	1	1	
26	0.28	1	6	2	1	
27	0.281	2	6	2	1	
28	0.288	3	6	2	1	
29	0.287	4	6	2	1	
30	0.329	5	6	2	1	
31	0.389	6	6	2	1	
32	0.544	7	6	2	1	

Fig15: 12 month data of hourly consumption level for a commercial-type building

3.3.2 Following the same characteristics for our consumption

I used the consumption column as my distribution and did it as follows:

Firstly I combined the first month consumption amount which you see in the Monthly column.

Second step was to divide each of our month's consumption size with the 12 Monthly consumption size, and find the Scaling factor.

And at last multiply the consumption column to their scaling factors to find our distribution of our own consumption.

This is a common method used in many industries besides simulating our own data distribution(due to the consumption distribution being too random and not making any

sense), because there is a lack of dataset for making improvements or building something new.

	A	B	C	D	E	F	G	H	I	J	K
1	consumption	hour_of_day	day_of_week	day_of_month	month_of_year	Monthly	2023kWh	Scaling factor	Scaling factor	Scaled Wh	Scaled Wh
2	0.255	1	5	1	1	471.632	48,862.18	103.6023425	103.6023425	26.41859734	26418.59734
3	0.264	2	5	1	1	440.766	45,851.91	104.0277834	103.6023425	27.35101842	27351.01842
4	0.253	3	5	1	1	447.606	47,280.40	105.6295045	103.6023425	26.21139265	26211.39265
5	0.25	4	5	1	1	430.063	37,680.31	87.61579117	103.6023425	25.90058563	25900.58563
6	0.234	5	5	1	1	447.136	32,000.83	71.56844897	103.6023425	24.24294815	24242.94815
7	0.249	6	5	1	1	553.133	19,154.75	34.62955564	103.6023425	25.79698328	25796.98328
8	0.297	7	5	1	1	603.37	15,123.72	25.06541591	103.6023425	30.76989572	30769.89572
9	0.323	8	5	1	1	597.598	24,765.65	41.44198943	103.6023425	33.46355663	33463.55663
10	0.423	9	5	1	1	496.894	33,094.03	66.60179032	103.6023425	43.82379088	43823.79088
11	0.418	10	5	1	1	453.63	46,171.80	101.7829509	103.6023425	43.30577917	43305.77917
12	0.418	11	5	1	1	450.771	54,713.03	121.3765526	103.6023425	43.30577917	43305.77917
13	0.431	12	5	1	1	504.4808684	64,251.31	127.3612421	103.6023425	44.65260962	44652.60962
14	0.424	13	5	1	1			103.6023425	103.6023425	43.92739322	43927.39322
15	0.424	14	5	1	1			2	104.0277834	103.6023425	43.92739322
16	0.426	15	5	1	1			3	105.6295045	103.6023425	44.13459791
17	0.419	16	5	1	1			4	87.61579117	103.6023425	43.40938151
18	0.423	17	5	1	1			5	71.56844897	103.6023425	43.82379088
19	0.434	18	5	1	1			6	34.62955564	103.6023425	44.96341665
20	0.393	19	5	1	1			7	25.06541591	103.6023425	40.7157206
21	0.367	20	5	1	1			8	41.44198943	103.6023425	38.0220597
22	0.356	21	5	1	1			9	66.60179032	103.6023425	36.88243393
23	0.313	22	5	1	1			10	101.7829509	103.6023425	32.4275332
24	0.288	23	5	1	1			11	121.3765526	103.6023425	29.83747464
25	0.284	24	5	1	1			12	127.3612421	103.6023425	29.42306527
26	0.28	1	6	2	1				103.6023425	29.0086559	29008.6559
27	0.281	2	6	2	1				103.6023425	29.1125824	29112.5824
28	0.288	3	6	2	1				103.6023425	29.83747464	29837.47464
29	0.287	4	6	2	1				103.6023425	29.7338723	29733.8723
30	0.329	5	6	2	1				103.6023425	34.08517068	34085.17068
31	0.389	6	6	2	1				103.6023425	40.30131123	40301.31123
32	0.444	7	6	2	1				103.6023425	56.04886730	56048.86730

Fig16: Hourly consumption distribution dataset

Now we can visualize our daily consumption,

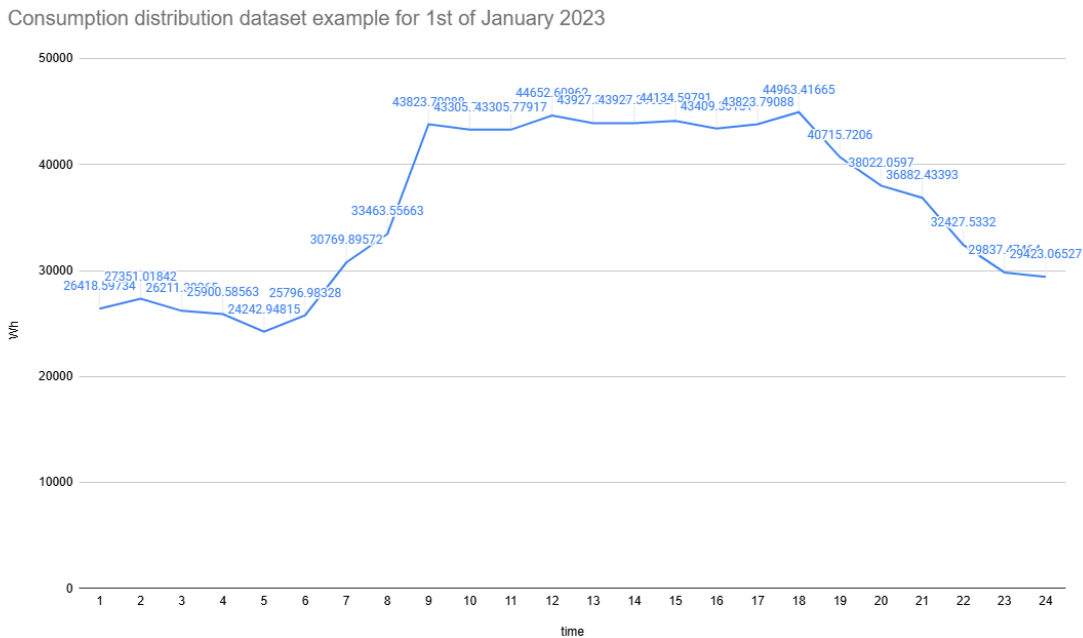


Fig17: Consumption distribution dataset example for 1st of Jan/2023

3.4 Photovoltaic design

For my solar panels I choose from a Chinese company called, Leeline Energy where they make 800W with efficiency of 21.6%(used for land use) solar panels for commercial buildings, and their sizes are 2279*1134*35mm, meaning 2.279meter *1.134meter=2.58 meter square per solar panel. They are Mono crystalline modules with a lifespan of 30 years guaranteed. And 30 years lifespan is more than average than other solar panels ranging from 20-25.

For my simulation of photovoltaic power system, I chose PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM that let's me choose where I want to put my solar panels, with how much peak PV power I want to install, choose the mounting options(which is for slope is 31 degrees during summer, 52 degrees during autumn, 62 degrees during winter, 50 degrees during south all facing south, and for our website 0 degree azimuth and the values I mentioned are optimal in Mongolia), and system loss which is usually 14 percent. This site uses simple calculation method as follows:

$$\text{Energy output} = \text{Irradiance} \times \text{Panel Area} \times \text{Efficiency} \times \text{PR}$$

Let's me visualize my results as follows:

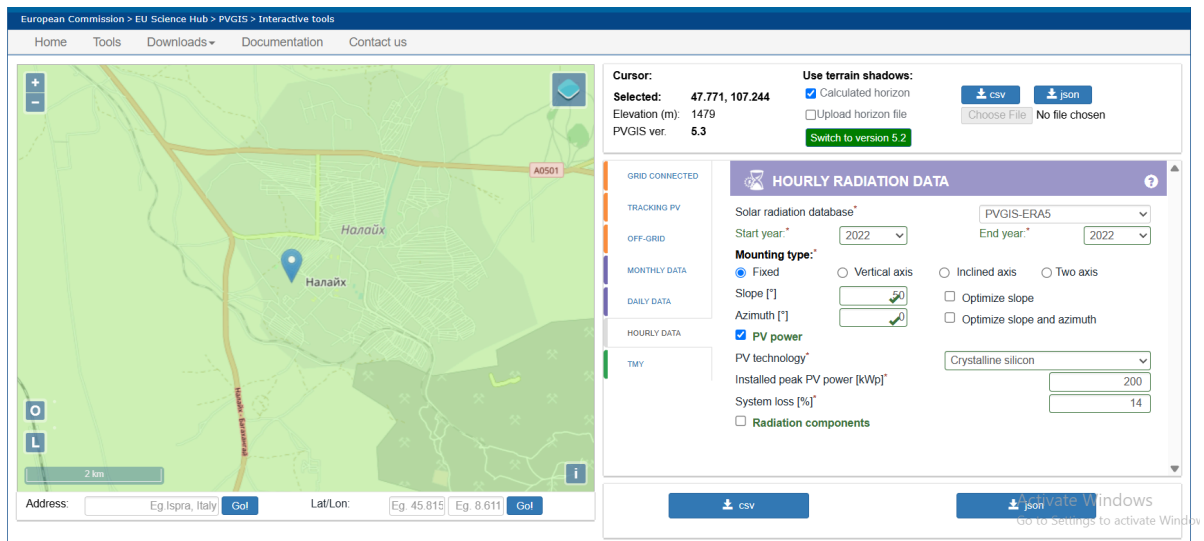


Fig18: Photovoltaic Geographical information system example for spring

Simulated for every season with their following mentioned angle with the installed peak PV power being 100kW.

Size of our PV system

When we calculate the size with these solar panels we get:

$$200\text{kWh} = 200000\text{Wh}$$

$$\text{Solar panel count} = 200000\text{Wh} / 800\text{Wh} = 250 \text{ solar panels}$$

$$\text{Size} = 250 * 800W / (1000W/m^2 * 0.216) = 925.9384m^2$$

For AC wiring we would have to use 120 mm² for current of $I = P / (V * 3^{1/2})$ which is continuous 290A.

3.5 Wind farm energy

Of course, as we mentioned earlier, to build a wind farm, its initial cost would be absurd, but we can make a contract with an already built wind farm company to completely make our campus use green energy. Our closest available wind farm is the Salkhit wind farm owned by Clean Energy that is 42 km away. They have 31 individual wind farms that have a capacity of 1.6MW, combined they make 49.6MW. They produce an annual power output of 168,500MW and their commission date was in 2013. So let's say we make a contract to use one of the 1.6MW nameplate capacities 20%. That would mean from the total output of 168,500MW we divide it by 31, is 5,435.5MW output by each wind farm. So our annual energy consumption was 496,425.41kWh in 2023 and 468,949.92kWh in 2023. If we take only 0.0000735% of one of the wind farms, which would be $5,435.5MWh * 0.0000735\% = 399.5kWh$ of annual power production.

The one upset is that the average pricing for 1kWh energy to make contracts are classified. But from 2007 when renewable energy sources were being introduced to Mongolia, they market capped the price for wind energy at \$0.095(338.26mnt), and solar energy at \$0.18(640.92mnt) which are very high. Eventually the wind energy and solar energy was reduced to \$0.085(302.6612mnt) and \$0.12(427.2864mnt). But for long term contracts they do reduce the pricing for both of these renewable energy sources, for example in China goes for \$0.035–\$0.055, and in the US goes for \$0.020–\$0.040(Also one time cost ranging from \$10,000–\$50,000 when negotiating a small PPA).

A case study in China would be that the feed-in tariff for wind effective in 2009 was between 51 and 61 cents, and started decreasing from 2010 to 35 cent. This could be the case for Mongolia, considering they have to match the price for the Renewable energy to the coal in order to be affordable.

So let's say an optimistic \$0.05 which is 178.036 mnt.

Wind farms will step up the voltage using a transformer to our substation and stepped down for our local use, that means we will be using a 10kV wire that has a resistance of 0.641 Ω /km(50 mm²)

43 km away from our substation, so the resistance is 27.563ohm(our peak power consumption in 1 hours was 173kWh, but let's use 300kWh for future load increase)

Current will be $P/\sqrt{3} \cdot V=300\text{kW}/\sqrt{3} \cdot 19\text{kV} \approx 17.2\text{A}$

$P_{\text{loss}}=3 \cdot I^2 \cdot R=3 \cdot 17.2\text{A}^2 \cdot 27.563= 49.1\text{kWh loss}$

If $400\text{ V} \times \sqrt{3} \times 430\text{ A} \approx 298.2\text{ kW}$ was delivered

The loss in percentage is $49.1/298.2=16.5\%$

Which 16.5% is very large for our power system, so we can use a thicker 95 mm^2 Al wire to reduce loss to $\sim 8.3\%$.

3.6 BESS

The technology for BESS is based on the use of electrochemical storage, which can store the energy produced by renewable power plants. It's a kind of power bank that can give back stored energy, by returning it on demand. As in all storage systems, in the case of BESS the electricity produced by a power plant, or any other generating plant (even a single photovoltaic panel), is stored and then released at the desired times and moments.

BESS consists of:

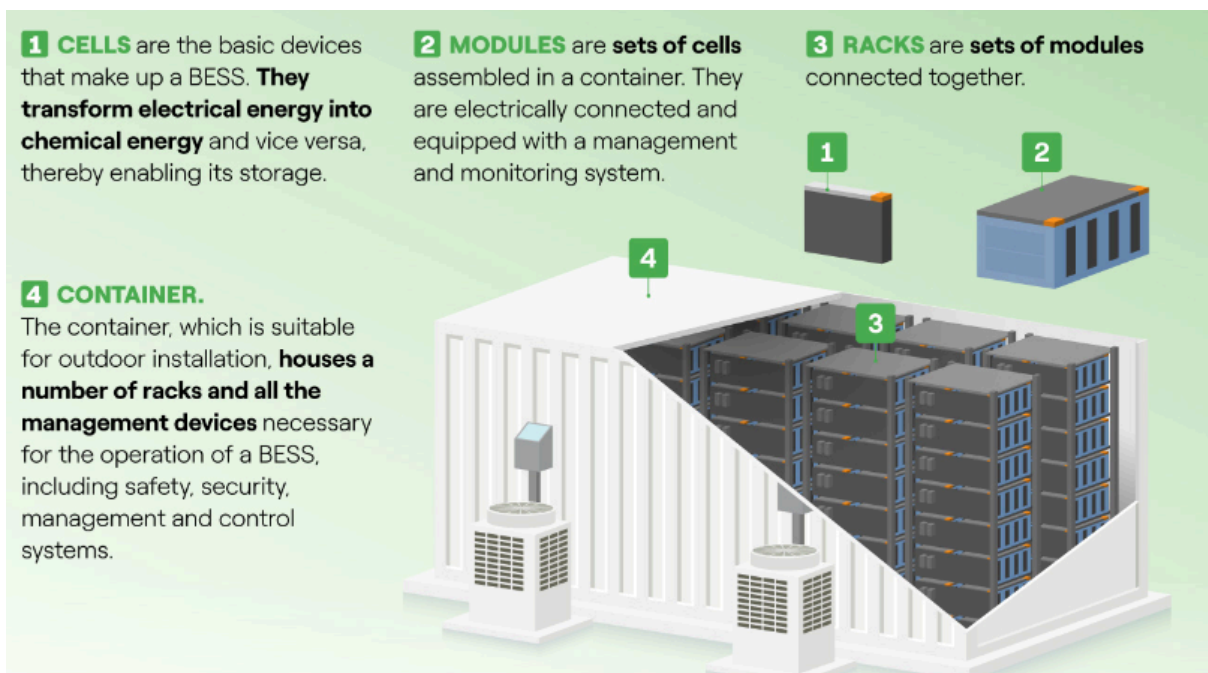


Fig19: example of a Battery storage

- Inverter/Converter (Bidirectional)

Converts DC from battery to AC for grid and vice versa

- Battery Management System (BMS)

Ensures safe charging/discharging

Monitors voltage, temperature, and state of health

- Energy Management System

Enclosure & Cooling

Weatherproof cabinet or containerized system

- Protection and Control Systems

Circuit breakers, relays, grounding, surge protection

Size of our BESS system



Lithium Battery Energy Storage Solar Power Battery 200kwh 300kwh Battery Container Price

US\$25,000.00-35,000.00

1 Piece (MOQ)

Port: Ningbo, China

Production Capacity: 200pieces/Years

Payment Terms: L/C, T/T, D/P, Western Union, Paypal, Money Gram, FOB

[Contact Now](#)

Fig20: Chosen battery storage image

Shenzhen Feise New Energy Technology Co., Ltd, a Chinese company that sells these 200kWh, 550kW output storage systems that range from 25,000 US dollar to 35,000 US dollar. While for this exact product's size dimensions are not given but a similar product called 200 kWh LiFePO₄, made by the same company, has a size of 1610 mm (L) × 900 mm (W) × 2050 mm (H). And the reason I picked this one is because it is made for indoor placement. That is a major factor considering, we can fit in our storage area, made of lithium ion batteries(which are the best batteries used for charging and discharging), size of the battery suits for our application, a 10 years warranty, and no land cost.

Chapter 4

Design, cost and sizing of Microgrid system at GMIT

4.1 Comparison of demand and production

Our annual consumption for 2023 and 2024 was 496,425.41kWh and 468,949.92kWh. But because of the increased consumption from January to May of 2023(most probably due to construction work), we cannot compare the annual costs for average annual consumption cost increase, so we will use the monthly data from August to December of 2023 and 2024. The average increase in monthly energy expense after a whole year was 42.50080043%. At least we could be looking at a power consumption of 668,253.636kWh to cover this amount our 200kW solar power system, and the 400,000kWh annual wind energy system will suit right in.

Our annual production together would be:

$368417.544\text{kWh}(200\text{kW installed PV cells})+400,000\text{kWh}(\text{from Salkhit wind farm})=768,417.544\text{kWh energy production}$

With the Salkhit wind farm's energy production is not given with hourly rate, we could estimate the hourly power production with mean wind speed(m/s) and air density.

These are the values in kWh starting from January to December. The values of wind, solar, and scope of 2025 were made synthetically. By using 2024 data we would have made excess energy of 300,00kWh, and by using the scope of 2025, we would have 100,000kWh excess energy that can be sold, used for heating. But we don't necessarily have to take 400,000kWh of annual energy, we can just make a contract with an approximation of how much energy we would be really using. This is a rough estimation, so using real life data for a whole year would be very useful.

kWh	wind	solar	2024	dif of 2024	2025	dif of 2025
Jan	21930.79339	30163.934	48,862.18	3,232.55	69628.6065	-17533.87911
Feb	29853.07529	33755.59	45,851.91	17,756.76	65338.97175	-1730.306464
March	36087.9184	35317.826	47,280.40	24,125.34	67374.57	4031.174398
April	38328.94248	33647.45	37,680.31	34,296.08	53694.44175	18281.95073
May	43773.43196	32640.97	32,000.83	44,413.57	45601.18275	30813.21921
June	36211.53781	29964.442	19,154.75	47,021.23	27295.51875	38880.46106
July	33505.25214	30338.546	15,123.72	48,720.08	21551.301	42292.49714
August	31954.94309	28900.804	24,765.65	36,090.10	35291.05125	25564.69584
Sep	37626.91255	29756.698	33,094.03	34,289.58	47158.99275	20224.6178
Oct	30691.22167	29122.528	46,171.80	13,641.95	65794.815	-5981.065329
Nov	26220.31952	27054.378	54,713.03	-1,438.33	77966.06775	-24691.37023
Dec	33815.6517	27754.378	64,251.31	-2,681.28	91558.11675	-29988.08705
	400000	368417.544	468,949.92	299,467.62	668253.636	100163.908

Fig21: Generation vs consumption

Winter seasons have the highest demand for energy, I have made a graph for a day, and it looks like this:

Total generation and consumption example of 2024 21st of December

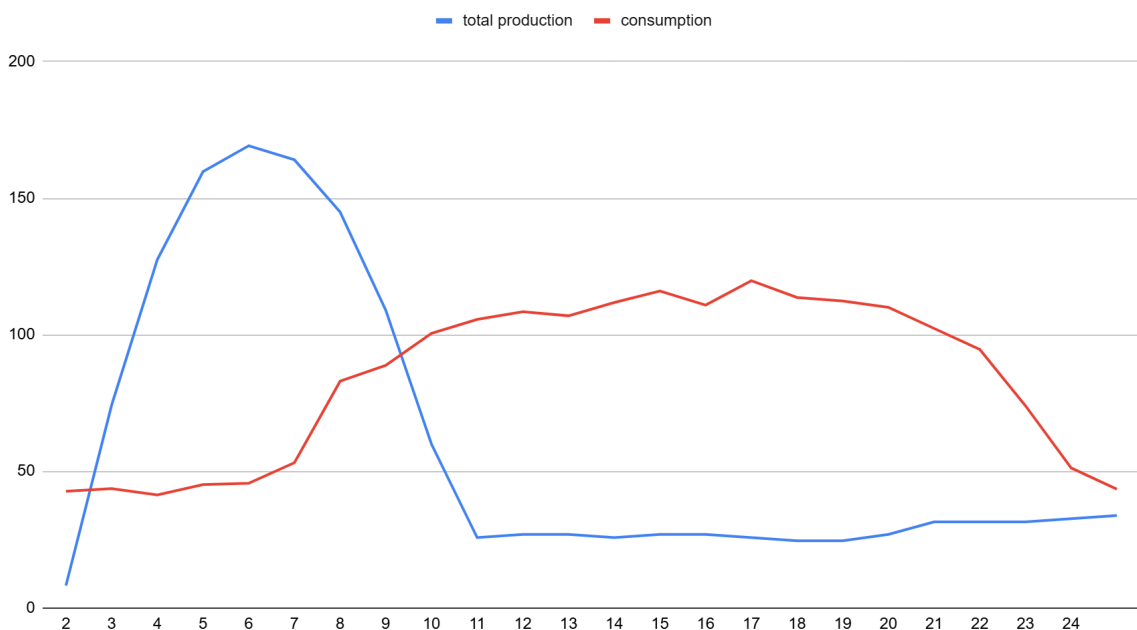


Fig22: Total generation and consumption on 21st of December

Of course, as I mentioned we cannot make a contract on exactly how much energy we would be using because the production and energy consumption ratio could look like this. We stored 513.702156kWh of energy from 1am to 9am, but the rest of the load cannot be supplied if we are in islanded mode, and make a contract to use exactly how much kW of installed wind farm. So we need to stay grid connected in case there is an unplanned outage at the wind farm, and just make a contract to buy their energy for a fixed price(which should be lower than the conventional source).

4.2 Electrical schematics

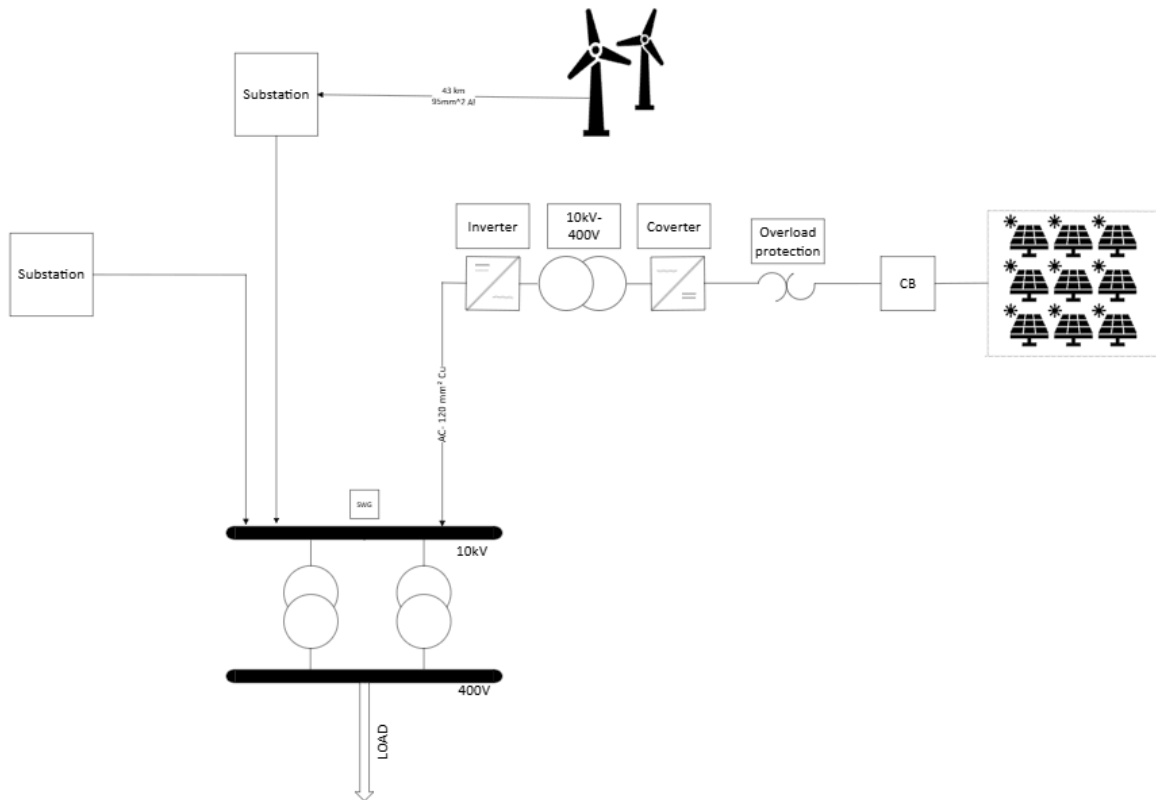


Fig23: Electrical schematic of microgrid configuration

We connect both renewable energy sources to our AC bus, even though hybrid microgrids are flexible for adding new renewable sources, but the rest of sources are not feasible, and are high cost for implementation. We will need to monitor, protect and optimize the solar panels ourselves so I added a CB with overload protection for safety measures.

4.3 Cost of the system

Another key expense is the ongoing maintenance and operational costs. Regular energy systems monitoring, predictive maintenance, and technical upgrades contribute to predictable maintenance expenses. Industry benchmarks indicate that annual operational costs can represent as much as 10-15% of the original capital investment, which covers labor, spare parts, and technology integration with existing infrastructure.

4.3.1 Photovoltaic design cost

Assessing the United States (mostly global)' Solar Power Play, Published on July 1, 2024 says that, today, China dominates global solar manufacturing with over 80 percent market share, producing panels that cost as little as \$0.10 per watt (But averaged to \$0.15).

So if we take that argument and use it for our solar panels cost, it would be: $200,000W * \$0.15 = \$30,000$ with today's average mnt to dollar is 3560.72mnt = \$1, meaning, $\$30,000 = 106,821,600\text{mnt}$.

Other components include:

Converter= Huawei SUN2000-50KTL, \$3,000

A bi-directional inverter Max. efficiency of 98.6%, 5 years warranty.

Inverter= 1799\$

Mounting Structure=30\$-45\$ per kW

Cabling and Wiring= \$15-\$25/m

Combiner Boxes= 250PV panels, meaning 250panels/25panels/string= 10 strings, for a 16-input combiner box costs \$235.

Protection Equipment (Includes fuses, breakers, surge protectors, and isolators)=

Protection equipment should always cost 3-7% of total project cost for a large microgrid.

Voltage sensor at inverter= \$50-\$150

Labor, shipping, foundation= \$8000

Wiring (DC and AC cables, Grounding cables, Conduits and trays)= \$5000

4.3.2 BESS cost

As we discussed earlier, our battery system is a 200kWh that can output 50kW per hour, ranging from 25000-35000 USD (which is 89,018,000-124,625,200mnt).

Other components include:

Sensors (voltage, current, power meters)= 3%

Battery Management System (BMS)=

Power Conversion System= 30%

Cooling and HVAC= \$3800

Wiring, Protection, Switchgear= 4-8%

Communication System (SCADA integration) or Monitoring System= A Centralized SCADA or EMS (Energy Management System) should always cost 2-4% of the total project for large scale microgrids.

Sensors =3%

4.4 Total land cost

This post was found on Vnegvi.mn and was the nearest available land being sold, so I took this example for my area calculation. But if we look at areas that don't have a population near it, with minimal chances of people wanting to build homes or other buildings, that kind of area will probably cost much less than this example.

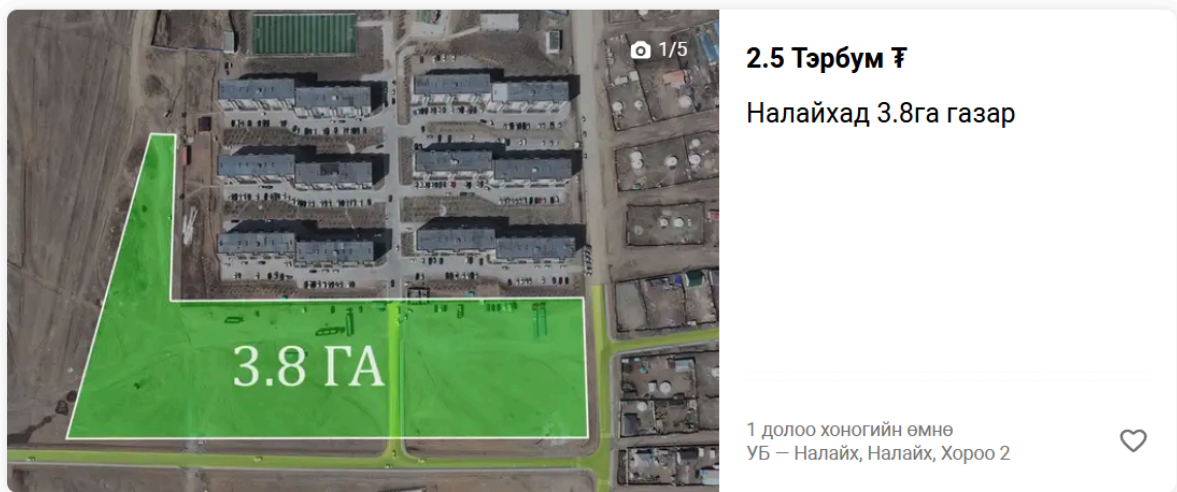


Fig: Vnegvi.mn land cost example

3.8 hectares= 38000 square meter

Price for a square meter land was approximately $2,500,000,000/38000$ square meter = 65,789.5mnt per square meter

So, our PV land area will cost us $925.9384\text{m}^2 * 65,789.5\text{mnt}/\text{m}^2 = 60,916,195.42\text{mnt}$

Chapter 5

Results and Discussion

Mongolia is a developing nation with enormous fossil fuels, but has a high potential to build more green energy, and our campus can be one of the first to inspire many. Without any monitoring equipment, it would be unfair to say these values of solar, wind, and power consumption are correct but are valid for designing a microgrid system. We made a model of our consumption with another campus's consumption to show and decide on our generation of our PV which we chose 200kW for our peak installed power and how much more energy we would need from wind farms with our contract that should be lower to equal the lowest amount of the three tariff systems. This way our whole demand can be met with green energy.

My suggested system is an AC microgrid that uses solar and wind energy to meet campus load, and uses a BESS to insure security, reliability, and cost efficiency. When we have enough stored energy to feed our campus for a few hours, we would go into island mode to use the stored energy, while only collecting energy from the solar panels. When we have excess energy we can always sell it back to the local substation, use it for heat, constructions etc. We should be able to monitor all of the power generation, power consumption, state of charge of the battery, and when there is an unexpected outage or problems involving the battery, we should be able to connect to the main grid and do maintenance.

I didn't consider any personnel on the site for hire, because we want to have an automated system that can alarm us, and the company we make a contract to do maintenance on our microgrid, and be able isolate, and shutdown any malfunctioning part of the system.

Of course for a microgrid project to be feasible the microgrid must pay for itself within 7-10 years with a BESS. So let's see how long it will take for our system to pay itself.

Total one time cost			
Name	Cost of unit	Amount of unit	Total cost

PV			
Solar panels	427,286.4mnt	250	106,821,600mnt
Converter	10,682,160mnt	1	10,682,160mnt
Inverter	6,405,735.28mnt	1	6,405,735.28mnt
Mounting structure	106,821.6-160,232.4mnt per 1kW	200kW	21,364,320-32,046,480mnt
Combiner box	836,769.2mnt	1	836,769.2mnt
Wiring	18,253,600mnt	1	18,253,600mnt
Protection equipments	5%		5%
Voltage sensor	365,072mnt	1	365,072mnt
Set-up cost	36,507,200mnt	1	36,507,200mnt
In total= 211,827,848.92mnt-223,072,227.87mnt			
BESS			
Energy storage	89,018,000-124,625,200mnt	1	89,018,000-124,625,200mnt
Sensors	3%		
Cooling and Hvac	13,872,736mnt	1	13,872,736mnt
Wiring, Protection, Switchgear	8%		
Communication system	3%		
Set-up cost	10,952,160mnt	1	10,952,160mnt
In total= 127,913,366.29mnt-167,921,456.17mnt			
Life cycle cost Microgrid			

Maintenance	1.5%-2% net capital cost		8,602,945.2-11,470,593.68mnt
Wind farm			
Contract	36,507,200-182,536,000mnt	1	36,507,200-182,536,000mnt
1kWh price	178.036 mnt		

Table3: TLCC table

So in total 1 time cost would be ranging from 376,248,415.21mnt-573,529,684.04mnt in items, the total land cost being only the solar panels 60,916,195.42mnt, and the life cycle cost being 1.5% to 2% of original capital cost.

Our annual generation only depend on the PV energy production, and we know our 200kW PV system makes 368417.544kWh of energy, but it is hard to calculate how much we will financially benefit from them because we don't know at which time of our 3 tariff system it would be used.

By combining the PV and wind farm energy we can estimate how much energy we would be saving. But we do have a distribution of our solar energy which we can use for mid-load, and high-load demand period.

From our modeled consumption data, we can see during the mid demand period was in total 269106.2196kWh, during the high high period 116267.9223kWh, and during low demand period was 83564.54817kWh. If we take these in percentages they are,

Midload	5738622666%
Peak hours	2479384294%
Off peak hours	178199304%

Table:

If we take these values and multiply them with respect to their cost per kWh, it adds up to 145,409,131.3mnt but in our transcript we spend a total of 100,014,537.48mnt in 2023. Which means we spend more energy during off peak hours than our modeled consumption characteristics.

We know how much energy we consume and how much money it costs. We can calculate the amount of money we would spend if we had the 2023 energy consumption. Because we don't have data previous from 2023(because there was a

new company that managed our power system starting from 2023 and only has records of 2023 and 2024), we can only use consumption and cost data from 2023 and 2024.

So, in 2023 we used 496,425.41kWh of energy, and paid 100,014,537.48mnt, and 2023 used more energy than 2024. If we used the same amount of energy in 2024, in 2025, let's see how much we would save.

Our Solar panels would be generating 368417.544kWh of energy, which means the remaining energy we need to generate would be 128,007.87kWh which will be fed by the Wind farm contract we made. Even though the market cap for Wind farm 1kWh energy is \$0.085(302.6612mnt), in order for Wind farms to make contracts they would have to a little more or equal to the 1kWh energy price of conventional sources which the minimum value of 3 tariff system is 185mnt. So let's say an optimistic \$0.05 which is 178.036mnt is the price for 1kWh of energy, that means we will have to pay

Of course every year our university recruits more students than the last year's recruited students number, and the load for the school is increasing due to more students studying on their own, still doesn't give us how much load will increase in these next few years. But the more load we have in that year, the more money we would save by using green energy sources. The solar panels will output a fixed amount of energy annually, while also tilting the solar panels in every season for maximum efficiency, and the rest of load will be carried out by the wind farm contract that has a potential to be low as the off peak hours cost of 160mnt/kWh.

Unlike our closely placed solar panels, the wind farm is 43 km away, so we have to take the loss percentage of 8.3 meaning on top of our total consumption.

$$128,007.87kWh/91.7*100=139,594.18kWh$$

$$139,594.18kWh*178.036mnt/kWh=24,852,789.43mnt$$

$$100,014,537.48-24,852,789.43=75,161,748.05mnt$$

But if we had the microgrid and these renewable energy sources in 2023, we would also have to pay for the lifecycle fee for the microgrid which ranged from 8,602,945.2-11,470,593.68mnt, so minus the annual life cycle cost being comes up to 63,691,154.37-66,558,802.85mnt.

Until we have further information on consumption data, and information on contracts we could make with the nearest wind farms, at minimum considering next year's load will be more than the previous ones, we expect our microgrid to pay itself within 5.652872-9.00485years (considering we have the same 2023 energy consumption for these years).

9.00485 years is a very long time, but considering the fact that when load increases, we will be paying back our microgrid faster.

Summary

The development and proposed implementation of a hybrid microgrid system at GMIT represents a critical step toward enhancing energy sustainability, reliability, and educational innovation in Mongolia. This thesis has demonstrated that with accurate load profiling, resource assessment, and component sizing, a renewable energy-based microgrid can not only meet the campus's electrical demands but also offer long-term economic, environmental, and academic benefits. Careful analysis of the campus's monthly and hourly energy consumption—despite limited existing datasets—enabled the development of a realistic demand profile through data modeling, ensuring that the system is designed to closely match actual load characteristics throughout the year.

The feasibility study confirmed that the Nalaikh district possesses substantial solar potential, making PV the most practical on-site generation source, while wind energy is better utilized via a contract with the nearby Salkhit Wind Farm. This approach provides a scalable path to 100% renewable energy use without the heavy capital burden of installing and maintaining wind turbines directly. The chosen 200 kW PV system, composed of 800 W high-efficiency monocrystalline modules, is space-efficient and optimized for Mongolia's solar angles across seasons. Meanwhile, the 200 kWh lithium-iron phosphate BESS provides reliable load balancing, peak shaving, and backup power during grid outages—critical functions given the frequency of blackouts experienced on campus. The proposed BESS solution includes all required safety, monitoring, and thermal management systems, ensuring operational reliability and regulatory compliance.

Beyond the technical and economic aspects, this microgrid project serves a broader institutional and societal purpose. It establishes GMIT as a model for sustainable campus development in Mongolia, demonstrating how educational institutions can lead the transition to clean energy. By incorporating smart monitoring, metering, and control systems, the microgrid provides a rich, hands-on learning environment for students and researchers in electrical engineering, renewable energy, and system integration. It also prepares the campus for future smart grid applications and lays the groundwork for developing local technical capacity in microgrid design, maintenance, and optimization.

In conclusion, the proposed microgrid system is more than a technical solution—it is a transformative opportunity for GMIT. It ensures energy security, supports Mongolia's renewable energy targets, reduces operational costs, and enhances the university's role as a leader in green innovation. With thoughtful execution, the GMIT campus

microgrid can serve as a replicable model for other academic institutions and small communities across Mongolia and Central Asia, accelerating the region's sustainable energy future.

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