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Research article

Evaluation of techno-economic design andimplementation of solar-wind hybrid microgridsystem for a small community

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ABSTRACT

Pakistan is faces significant challenges in meeting its energy demand and consumption needs for consumers. This country's energy production from primary sources such as petroleum and natural gasses is incompetent in fuel-use and hence unable to meet feasibility cost. With an increasing population, Pakistan's energy consumption per capita has been steadily rising. This behaviour is leading to critical energy issues, especially in remote rural areas. This trend in rising energy costs and demand factors are similar to those in the energy markets in the South and South-East Asia. The primary energy sources in Asia continent, including fossil fuels, are insufficient supply to meet this growing demand in production and thus resulting in frequent electricity blackouts. Consequently, renewable energy sources such as solar photovoltaic (PV) and wind power have substantially started to produce energy and to provide a huge portion of Pakistan's daily energy needs apart in conventional energy currently. However, these sources are not yet as reliable, conventional energy bases have a challenge for sustainable energy production. As a result, renewable energy factors nonetheless initial started have effectively stabilized energy consumption, particularly for green electricity with net-zero carbon emissions. The aim of this study is to evaluate the feasibility and cost-effectiveness of integrating a microgrid hybrid system with combined (solar PV/wind power) renewable energy as well as conventional fossil fuel generators. This evaluation focuses on predicting energy production and its costs using Hybrid Optimization of Multiple Energy Resources (HOMER) software, and to enhance the electricity standards at NUST (National University for Sciences and Technology), Pakistan. The proposed methodology of microgrid hybrid system, when evaluated using HOMER software, shows a significant improvement in energy stability and cost efficiency. Moreover, this proposed system can reduce reliance on fossil fuels by a substantial percentage, enhances the predictability of energy production, and optimizes its energy consumption. These can achieve better performance metrics in terms of reliability, cost, and environmental impact; feasible solution for Pakistan and the developing countries. This proposed methodology offers a novel approach by integrating renewable energy sources with conventional generators to create a balanced and efficiency factor by microgrid

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system. This hybrid system goals as an investigation is to optimize this energy production, reduce carbon emissions, and provide a more stable and cost-effective energy supply.

1. Introduction

The power industries of numerous developing nations with vital components such as lack of motor machineries' performance or poor maintenance for continuously reliability serves increasing energy demands. Hence it takes a long-term progress for boosting their productions. But as the population in these developing countries grows, so does the demand for this energy. Therefore, these factors above have led to an increase rate in both power unit ~~failures~~ and the energy demand crises. Due to these extreme strains, the situation has not having such place in this energy-economic on developing countries, especially on their indigenous resources. In fact, this economic status is to have much expensive sources and costly imported electricity. The conversion of fossil fuels is one example [1]. Crude oil which is extracted from under land or sea's reservoirs by using the drill mechanism is providing conventional energy that functions with daily machines' systems. Despite the positive conventional energy productions, this petroleum liquid has been supplying usage for a limited period. If the crude oil production has no such liquid left from reservoirs, what will be the the next primary sourse for energy production.

The traditional means of producing electricity are using these fossil fuels as its ~~the~~ primary way currently. However, the processes have such significant production costs and thus leads to major environmental problems, greenhouse gas emissions increasing and climate change [2].

The greenhouse emission such as carbon dioxide (CO_2) and carbon monoxide (CO) gasses has now caused the climate change into extreme condition. These environment changes are even more risk function because they are exceedingly too much toxic gas outlets from these conventional energy as their primary fuel system. These harmful gasses could be such precipitation methods while moving in toxic clouds from the biggest cities where most of these industries are in place locations, to the urbanization and remote rural areas. These harmful gasses are causing too much risk of humans' life such as lacking breathing system due to more CO_2 emissions. It can cause furthermore the heatwaves and air-pollution rainfalls (acid rain) as well. So, conventional energy is a substantial risk factor due to its contribution to the maximum scale of greenhouse effect, even though its fuel machinery performance is more efficient. In addition, electricity that has producing function from this conventional energy fuel is another peril factor where a lot of greenhouse gasses has been produce and deposit in the atmosphere ozone layers. So can these machines work without crude oil.

Furthermore, the availability of electricity between rural and urban regions are currently present having huge cost too because of fossil fuel over-price method. Fossil fuel reserves are being rapidly depleted function due to the rapid increase in global electrical energy consumption. Additionally, several factors for such electricity encounters, including inadequate planning and policy, political unrest, a lack of power capacity, and expanding economies and sectors, could contribute to the prevalence of these power crises in the emerging nations. Thus, this type of power crisis can lead to such argument in terms of production in local goods; unable to meet their profit in market daily. Hence these productions are having dangerous economic balance system regarding on this energy, not only in Pakistan but in the South and South-East of Asia's markets.

As a result, many developing nations struggle to balance this supply and demand for energy nowadays. This drawback can result in hazardous energy production from either installed transmission capacity that causes electricity flow into shortages towards consumers or else undeveloped generating sectors to provide less units to it. To preserve such sustainable development feature and to save the environment as well, developed nations are currently concentrating think-tanks on their attention for the power outputs and financial resources on such renewable energy technology nowadays. Hence, there are some positive remarks rather than maintaining energy with these fossil fuels.

Hence, a feasible choice for this economic cost in terms of energy and the sustainable production efficiency for these developing nations is the renewable energy. It is readily available in a variety of forms, inexpensive cost, and conveniently accessible. Moreover, this feasibly factor is possible into a clean environmental output with zero emission of carbon dioxide and other toxic gasses too. Among these renewable energy sources, the wind power and solar PV are mentioned in this research thesis as one property of the microgrid hybrid system. Given that they are both clean and limitless solutions, they are superior competitors against these current fossil-fuel energy usages. Thus, this microgrid hybrid can overcome possibilities with this current conventional energy as a challenger solution.

Consequently, these forms are thus reducing the need for fossil fuels and adding to the renewable energy assortments that are robust to fluctuations in the cost price. So, the renewable energy combined with solar and wind power can compete with this conventional energy despite the renewable energy takes such extended period to produce electricity rather than that of fossil fuels' production. So, how can we manage these energy sources to achieve the maximum optimization in the electricity output?

According to Nazir et al., 20 % annually within the past decade from 2020 has reached towards the worldwide wind power generator, especially for Wind Energy. It has estimated in 2018 that global capacity reached around 600 Gigawatts (GW), including a decreased by 32 % for wind power capacity in Europe. The world-dominant leader in the wind energy, China has installed its wind capacity approximately 221 GW, and is producing more renewable energy power as a third position of the world's wind energy capacity [3]. Hence, this wind power energy is an excellent choice as a renewable energy positive aspect.

The electric capacity structures of renewable energy storage systems are divided into two categories. These categories are called economical and technical factors [4]. The energy storage capacity is its configuration form that corresponding to the economic indicators of the power station's income and several cost. It is also having an economic factor in comprehensive of their operating cost regarding the optical storage system. The technical specification of renewable energy storage systems focuses on enhancing reliability while minimizing costs. This feature involves optimizing conditions based on load patterns and derived from solar and wind hybrid systems [5]. Thus, the discussion of the power supply reliability, economy, and environment features have such benefits in renewable energy resource as its objective function. It solves several complications based on the chaotic multi-objective, established on genetic algorithms for instance. However, there is a certain delay in meeting this load and the reliable power supply also has based on the renewable energy criterion factors in the environment issues such as lack of solar PVs' heat and slow wind pace. Therefore, this renewable energy function for optimize these machines' productions and electricity could be substantial issues compared to conventional energy usage.

Nevertheless, both solar PV and wind farms have complemented one another as their benefits and hence lessen their disadvantages of conventional energy producer factor while utilizing these renewable energy sources as maximum range. Consequently, hybrid renewable energy that combine with both solar and wind power are in place to address numerous problems as well as electric storage system for their financial gain. Hence, the hybrid renewable energy in terms of the microgrid system, in the National University of Sciences and Technology (NUST), Islamabad, Pakistan has such positive potential system to produce towards their energy outcomes. This microgrid system can reduce or optimize these conventional energy outputs in the future. The balance mechanism for this type of microgrid system can eventually get controlled instead of fully depending on the fossil fuel system continuously. Moreover, the cost of this microgrid hybrid system is such feasibly expenses because it uses both renewable and conventional energy as a balance scheme. For simulation, this type of microgrid system at NUST community can occur using HOMER software as to evaluate these percentage of energy data and the feasibility cost on these coordinates location.

System stability even though having uniformly function aspect of microgrid hybrid control strategies, is increasing of its demand for renewable energy sources. It also determined by the limited fuel resources and the need to reduce to the air pollution. These factors are to emphasize the importance of integrating Solar PV and wind power with their distributed loads. These kinds of renewable sources and their loads are often connected to the existing utility grid, which introduces intermittency and stability challenges. Achieving system stability involves managing optimal power flow through controlling converters effectively [6], the stability of these kind of energy could be challenging to provide electricity to the buyers.

Microgrid systems while in cost-benefit analysis are having to integral in terms of financial and environmental aspects of modern engineering infrastructure. They play a crucial role in energy production, ensuring a reliable power supply, and reducing greenhouse gas emissions. Although conducting a comprehensive cost-benefit analysis is challenging, comparing the expected outcomes with the costs can be tolerated by stakeholders which is essential for evaluating project in terms of feasibility. Despite their high cost-effectiveness in meeting with local energy demands, these analyses can help, guiding the development of clean power plants, minimizing harmful emissions and optimizing these hybrid energy systems [7]. Thus, the stability and cost analysis for the microgrid systems in terms of its renewable and conventional energy balancing status could provide a reasonable factor in meeting with this energy demands.

The comprehensive research of my thesis topic is in progress, focusing on the microgrid hybrid system in HOMER Software to generate electricity for the NUST community. The solar and wind data shown significant values by the simulation in this location. This electricity flow results from a balance of both renewable and conventional energy sources in simulations with daily duration states. If this simulation data proves effective in electricity generation, the same concept could be applied in real-world scenarios.

If this research thesis is successful, the fundamental function of the microgrid hybrid system in HOMER Software can be elaborated for use in other real communities and remote areas where electricity supply is challenged by long distances from centralized national power grids. Similarly, industrial sectors could implement this microgrid system by installing solar PV and wind power, and integrating them with conventional fossil fuel generators for their energy needs. This new method of generating electricity can reduce electricity bills. It is also decrease in producing toxic gas emissions. With fewer toxic gases in the atmosphere, the environmental impact would be significantly improved, promoting green energy for the future. Commercial establishments such as shopping malls

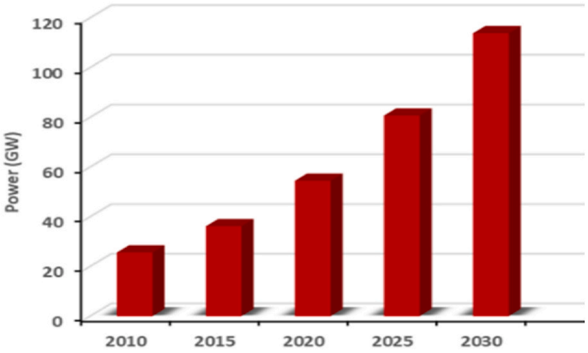


Fig. 1. Power demand - Pakistan.

could benefit significantly from implementing the microgrid hybrid system, utilizing natural input sources for electricity instead of relying on fossil fuel generators. Additionally, electric vehicles could be powered by the balanced microgrid hybrid system rather than conventional fuel vehicles, which currently contribute to carbon emissions. This statement underscores the potential applications of the topic.

2. Methodology

This methodology for the research thesis topic outlines a structured approach to researching renewable energy systems. It has focused on solar PV, wind Power turbines, and storage electricity cells in the NUST community, with an emphasis on technical and economic feasibility using HOMER software. The definition of the solar PV and wind power are given below.

The sunrays hit the solar panel, causing its energy to be absorbed by the PV cells. This type of energy can form into the electrical charges corresponding to an internal electrical field in these cells. When the electrical charges are transforming into charged electrons movement, then these charges can loop into the direct current electricity and hence causing a flow of electricity [8]. This is a principle of electricity.

According to an article composed on the solar PV capacity in Pakistan, there is an increasingly power factor in electric demand, around 8 percent per annually. This rising percentage has a surge factor in energy demand, causing its deficit feature to the electrical grid. Hence, renewable energy could be an ideal factor instead of fossil fuel charges to balancing this deficit energy. Fig. 1 shows the energy demand in Pakistan; power output versus the year duration and predicted year combined. This display shows the power needed in Pakistan (20 to around 110 power GW) between 2010 and 2030 year predicted forecasting values. This increase type in power demand can corresponding to the solar energy decentralized efficiency, broadcasting the supply and demand balance energy [9]. Decentralized energy production instead of main grid electricity, which occurs close to the point of consumption, allows for the optimal use of renewable energy, reduces the reliance on conventional energy, and increases economic cost efficiency for the buyers.

Another developing country is Sri Lanka, having solar energy efficiency recently. According to the Asian Development Bank (ADB), the solar PV and wind power in Sri Lanka will have reach 92 percent in power capacity that predicted in the year 2030. These renewable energy formulas will compete with Ceylon Electricity Board (CEB) regarding Hydro-energy electricity. This type of electricity when generated from solar PV has been estimated to be the cheapest amount compared to the primary electricity source, hydroelectricity by International Energy Agency (IEA), reducing its cost by 1.3 billion US$ expected in the future stage [10].

Wind turbines (renewable energy provider) is to use the wind flowing pattern, causing their propeller blades to rotate around a rotor. This specific function can charge its rotation in the generator component. This rotate of generator can produce electricity as its renewable energy resource [11]. Thus, this feature is the type of electricity coming from the wind power principle.

As a result, the wind power in Pakistan has discussed by the case studies that an estimated gross wind power potential as stated in 2022 is around 346,000 megawatt (MW). However, the installed wind capacity in Pakistan at the same year is only 1985 MW. This fact describes that only 0.37 % of total available potential is being utilized in wind-renewable energy source by Pakistan [12] combined with conventional energy's electricity. Nevertheless, there are huge amount of power in wind energy in Pakistan that comprises substantial electricity productions and to reduce with conventional energy productions.

2.1. Research methodology case study

This case study focuses on Pakistan, a developing country in South Asia and the 8th largest country with a population exceeding 225.1 million. Its land area spans 881,913 km (about 547995.33 mi) ^{2}, encompassing four main provinces: Punjab, Sindh, Baluchistan, and Khyber Pakhtunkhwa. In 2020, Pakistan's installed electricity generation capacity reached 37,402 MW and is expected to continue growing. The electricity demand from Pakistan's residential and industrial sectors exceeds 25,000 MW. However, the transmission capacity, which is around 22,000 MW, leads to an electric deficit of 3000 MW. This deficit results in a defective supply of electricity and frequent load shedding [13]. Hence, there are multiple electric issues in providing electricity grids to the consumers.

According to Ullah et al., in 2020 [2], 26 percent of Pakistan's population lived without electricity. The electrification rates for urban and rural populations in those times were 90 % and 63 %, respectively. However, the high installation, operational, and maintenance costs of proving electricity through transmission lines, especially over long distances have stance in significant challenges. Rural populations, often earning middle-class incomes, struggle to afford these costs, leading to frequent power outages. Since 2020, Pakistan's population growth rate is 6 %, with a 10 % growth in energy demand. To address these issues, renewable energy sources like solar PVs and wind power have been promoted instead of transmission lines, reducing greenhouse gas emissions.

As a result, there is an immense potential factor for wind and solar energy generation in Pakistan where 0.071 % of its area has utilized to be able to meet current power demand. The six solar PV and nine wind energy projects of 418 MW and 980 MW have been operational in this country in the last five years. In fact, this nation has an expected prospective of 2900 GW power units from solar power, installed capacity of 1 kW peak (kWp) to generate 4.1 kWh/kWp per day [14]. Similarly, the Wind-renewable energy reaches average speed of 7.87 m/s in the 10 % of the windiest regions in Pakistan due to ample resources. Thus, the installed capacity of wind and solar energy in Pakistan is approximately 1500 MW having to reach 4 % of its total installed capacity and 2 % of total generation [15]. So, these are the figures in Pakistan recalling the energy generation by Rafique et al. and Expanding Renewable Energy by the year 2020.

Comprehensive literature reviews are conducted to understand the current trends and the state of research in hybrid renewable energy systems (Microgrids). The outcomes of these reviews are further analyzed using the HOMER software. Specific solar and wind data, including solar irradiance and wind speed for the NUST region in Islamabad, are collected for this analysis. These data are displayed by the HOMER software in the topic: results and discussion. This approach aims to evaluate the feasibility and optimize cost of the performance of microgrid systems by integrating renewable energy sources with conventional generators.

The primary collected data includes energy consumption patterns, with appropriate solar PV panels, wind turbines, and storage cell models are chosen based on energy needs and environmental conditions. Configuration of the hybrid system requires parameters to be indicated for their performance.

For Solar PV, the chosen model is Trina Tallmax M plus, with a rated capacity of 0.345 kW, flat plate panel type, monocrystalline element material, and a maximum efficiency of 17.8 %. The stakeholders should invest at least US$ 143.76, according to the US Dollars-Pakistani Rupees cash conversion. The additional operational and maintenance cost is US$ 1.44 per year (Cheaper cost though), for a duration of 20–25 years, with a derating factor of 80 %. (Conversion source: May 29, 2024)

For Wind Power Turbine, the selected model is AWS HC 1.5 kW Wind Turbine, with a rated capacity of 1.5 kW, 3.2-m rotor diameter, and a lifetime of 20 years. Stakeholders should invest US$ 3217.46 for capital cost, with replacement and operational and maintenance costs of US$ 2502.47 and US$ 64.35, respectively. (Conversion source: May 30, 2024)

The storage energy cells selected are BAE SECURA SOLAR 10 PVS 1500 by BAE Batterien GmbH, with a nominal voltage of 2V and a string size of 6 values, resulting in 12 Voltage. Capital and replacement costs are US$ 196.62 and US$ 178.75 respectively, for a lifetime of six years, with negligible operational and maintenance costs. (Conversion source: May 29, 2024)

The HOMER Software can analyze these resources availability, load requirements, and system components, running simulations to analyze performance under varying conditions. Optimization features can find cost-effective results and efficient system designs, thereby estimating costs associated with installation, operation, and maintenance of NUST's electric loads.

Also, sensitivity analysis is conducted to understand how much changes in these input parameters (Solar, Wind, Storage, and conventional energy) affect system performance and financial cost. The proposal is evaluated by assessing potential environmental benefits and reductions in greenhouse gas emissions resulting from this implementation of the renewable energy system.

2.2. Data and components

The focus of this research topic is the sustainability of solar PV and wind power only at NUSTin Islamabad with the help of storage devices and generators (hydro-dam/fossil fuel conventional energy).

As depicted in Fig. 2 (Appendix 3) referred to as data and component topic), the solar PV cells (Trina Tallmax M plus – 0.345 kW) illustrate the solar irradiance output per hour (Y-axis) and day period (X-axis) respectively. Although the values remain consistently, the cost for optimization in terms of renewable energy may vary. The graph clearly indicates that the maximum solar irradiance occurs around the 12th hour, with a power output of approximately 0.20 kW.

Given that the days begin in January, around 180 days are affected by summer season. Consequently, the gap between hours should increase due to the extremely hot conditions experienced during this period compared to days 0–90 and 270 to 365 (off – summer season). This data effectively illustrates the power output from sunlight rays at this location.

The yellow areas (0.32–0.4 kW – Appendix 3) show significant solar PV output in the late duration of February month and between November–December months, though these periods have shorter bars compared to summer. This behaviour can have suggesting about 6 h of sunlight on the 11th and 12th months annually. Solar PV systems typically generate energy from 8 a.m. to 5 p.m., offering approximately 9 h of sunlight daily throughout in summer season per year. Hence, the electric load from this solar PV output within the Sun's heat waves duration. So, these parameters above regarding the Solar Power PV output can be forecasting the similar environmental conditions if there are no climate change on this location.

Appendix 4 (Fig. 3) depicts the wind power data leading to the community location of a windy environment. Otherwise, if there are no/little wind speed parameters, then this university has connected to other locations in Pakistan, in the north-western province (Khyber Pakhtunkhwa region). Nevertheless, the model called AWS HC 1.5 kW wind Turbine can rotate either clockwise or counterclockwise using its fin to produce alternative current output using the wind-generators. The ratio of current produced can depend strictly on the amount of wind area, circulating the impact of its fans' blades. Other factors affecting of wind power include the altitude of these blades and the direction of the wind flow.

According to the analysis of Appendix 4, the wind turbine power output illustrates kilowatts per hour on the Y-axis and forecast

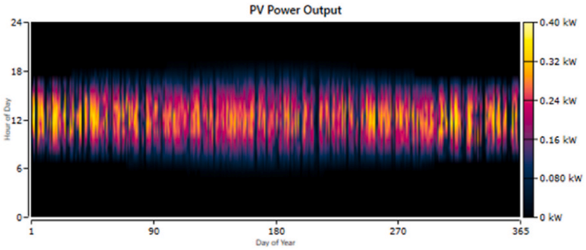


Fig. 2. Solar PV power output chart.

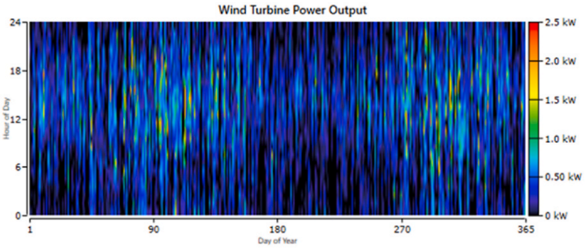


Fig. 3. Wind turbine power output.

days on the X-axis, like Appendix 3. The wind turbine produces AC (Alternating Current) current output consistently after 12 h throughout the year period, with a peak of 0.4 kW around noon every day. Around day 90 (March) and after day 270 (October), this scale turns into yellow colour, indicating a significant increase in power output to roughly 1.7 kW. So, there is the change in the wind speed throughout the hours corresponding to the amount of electricity being produce at this University.

On approximately the 50th, 240th, and 290th days, solar output reaches above 2 kW (dark orange to red) from 12 p.m. to 6 p.m., occasionally showing as 1.5 kW (yellow). Despite colour variations in Appendix 4, it is evident that consistent renewable energy production throughout the day offers a feasible alternative method into conventional energy. This microgrid hybrid system while balancing with other energy inputs and incorporating these wind power parameters, can have effectively efficient with produced renewable energy to the university's customers.

These two renewable energy sources, producing current output, are crucial for partially reducing fossil fuels and implementing alternative behaviours in the future times using this type of energy.

The fossil fuel-generator which is a part of conventional energy at the NUST 's microgrid system should have counted for this electricity because it should have a balance system with renewable energy formats. The community's location is big landscape although it is small size comparing to the landscape of Islamabad. The energy needed for this university cannot provide electric loads by these renewable energy output only. Hence, microgrid hybrid should have such balance scheme with this fossil fuel generators, although it can reduce this conventional energy down, having the ratio between the renewable and conventional energies and thus reducing this number of toxic gasses in this university's electric output.

Fossil fuels said by Ullah et al. are the conventional energy sources used for generating electricity forms [2]. As mentioned earlier, fossil fuels undergo such chemical reactions derived from crude oil petroleum liquid, extracted from underground or undersea reserves. These reserves are using the drilling mechanisms to bring out crude oil matter. This fuel liquid can have such efficiently to produce high-level electricity units, However, producing this electricity is at an excessive cost also. Hence this factor has significant environmental impact, including climate change, global warming, and greenhouse gas emissions. According to Ullah et al., 73 % of the world's electrical energy is produced by fossil fuels, while renewable energy sources contribute 27 %. The global annual electric energy demand growth rate is 2.7 % [2]. Consequently, developed countries are now investing in renewable energy technologies instead of prime conventional energy properties to balance this energy needs and to ensure such sustainable development. Therefore, this long-term economic gains of renewable energy in this type of microgrid system to be balance can have much enough of electricity units with no green gas emission afterwards. It also has a less amount of feasibility cost by reducing this conventional energy towards its balance status of this microgrid hybrid system and hence improvement with maximum renewable energy electricity.

2.3. Simulation setup

The simulation of renewable energy involves various software options. RETScreen software is one such tool, focusing on clean energy management and enabling low-carbon planning, implementation, monitoring, and reporting. However, the research thesis has opted to use an alternative software called Hybrid Optimization of Multiple Energy Resources (HOMER) software. This software allows for the analysis of renewable energy data at various locations, including residential areas. Therefore, I have chosen to focus on the University where I am currently studying. The location referring to Figs. 2 and 3 is 33° 38′ 55.77″ N, 58’ 35.43” E coordinates for this university, Islamabad. The Solar PV (Fig. 2) and wind power Map (Fig. 3) are mentioned in appendix 3and appendix 4 respectively.

HOMER Software encompasses numerous factors, including forecasting solar irradiances and wind power outputs, as well as combining converter storage devices to store electricity for future usage. The optimization cases and sensitive simulation attributes of these renewable energy systems enable the analysis of costs and prediction of circumstances ahead of time, which is a significant advantage.

Although HOMER software is commonly used for energy forecasting, other software options offer similar capabilities. For instance, Jupyter Notebook software, which I use for various research topics, excels in predicting energy outputs through machine learning and Python language programming. This allows for numerical outputs using specific algorithms. Another comparable software is Orange Data Mining, which also employs machine learning algorithms to predict and evaluate the performance of microgrid hybrid systems with efficient data and visualization matter. Despite these alternatives, HOMER software remains ideal for evaluating long-term energy parameters.

3. Results and discussions

The results from the HOMER PRO Software regarding the solar PV power and wind farming sectors have shown significant impact. These values represent larger renewable units compared to rural areas in Pakistan.

The location for this simulation was selected as the NUST in Islamabad, and its parameters are viewed aerially as depicted in Fig. 5 (Enlarge size: Appendix 7). The University or small community coordinates are noted in Fig. 5, automatically tracking its longitude and latitude precise values. Fig. 4 (Appendix 8) displays the satellite image of the small community, Islamabad. Additionally, Table 1 shows the discount rate and inflation rate percentages at that location while collected data. These percentages can be obtained from the State Bank of Pakistan, which provides forecasting tables. The annual capacity shortage percentage and project lifetime years are common values compared to latest trends in Pakistan.

Once the location is established by the software, the electric load data are counted for by the electricity provider, including various visualizations such as bar charts and scaled data. Table 2 listed the hourly load set for NUST, measured in kilowatts (kW). January was selected as the first month for electric load.

Table 3 (Appendix 9) displays the electric load in kilowatts per hour by the University Community, Islamabad on workdays only. It presents the monthly data presently available and could potentially include forecasting data as well. The term electric load on weekend is similar data in kilowatts as weekdays. However, there are a few conceptual differences now giving the data on both weekdays and weekends due to common presumptions.

Two notable cases arise from this comparison: Firstly, the weekday morning hours (9 a.m.–3 p.m.) should exhibit higher data compared to weekends due to increased use of electricity facilities during weekdays. Secondly, the electric load during weekends' evenings (5 p.m. till 10 p.m.) should be larger value than that on weekdays due to regularly gatherings by Nustian students. Hence, it is possible that the HOMER Pro Software may or may not have some inaccuracies when it comes to distinguishing between weekdays and weekends data. Hence, this software is not 100 percent accurate in its simulation results. However, it can provide positive forecasting for renewable and conventional energies, as well as feasibility costs for these components, rather than attempting to rely on unpredictable results.

Nevertheless, the data for both weekdays and weekends are measured in kilowatts per hour for the location usage. Hours 18 and 19 (between 6 p.m. and 7 p.m.) exhibit the maximum kilowatt values throughout the monthly range. Conversely, the lowest kilowatt values throughout the month (appendix 9) are recorded during hours 1 and 2 consecutively (1 a.m.–2 a.m.).

Next, this electric load has a bar chart in Fig. 4, similar units for kW and hours represented by graphically. For the Small Community (NUST) in Islamabad, the highest bar chart (electric load is almost 1.5 kW) occurs between 6 o'clock and 7 o'clock in the evening, while the lowest one (approximately 0.2 kW) is figuratively from 1 o'clock to 2 o'clock in the morning. Therefore, there is a higher kilowatt per hour during the evening time, which can be compensated with other bar charts to maintain a neutral balance.

A whisker box plot in Fig. 5 (Appendix 10) is displayed between the load kW and the monthly time at the University, Islamabad. This box plot diagram represents the minimum (lowest range), first quartile (Q1 - 25 percent range), median (Q2 - 50 percent), three-quartile (Q3 - 75 percent), and the maximum range (highest). An example represents the seasonal profile in November month. The minimum value is exactly 0 kW, while the Q1 value is approximately 0.15 kW. The median value for the electric load in November is close to 0.5 kW. The Q3 and the maximum ranges of the electric load are approximately 1.5 kW and 2.4 kW, respectively. Hence, other months' electric loads can be depicted by forecasting these values.

The kW heat map per hourly interval is depicted in Fig. 6 (Appendix 11). It shows that most of the colour in this map is dark blue, indicating approximately 0–0.5 kW per hour. As the "Daily Profile" (Fig. 6) illustrates, the hour of 6 p.m. shows significant changes from blue colour (0–0.5 kW) to yellow-orange colour (1.5–2.0 kW), suggesting that more electricity is being used by the small community, Islamabad, during this time.

The heat map visualization for power demand reveals intriguing consumption patterns Fig. 8. Dark blue (0.5 kW) indicates consistent low energy usage in the NUST. Occasionally, spikes of 1 kW (light blue to light green) signify periods of increased demand. Intermittent appearances of 1.5 kW (green to dark yellow) and rare instances of 2 kW (yellow to orange) suggest occasional higher usage. Very infrequently, 2.5 kW (dark orange to red) is observed. Understanding these patterns can inform effective energy management strategies for the community. Appendix 11 diagram may not have such high resolution because the heat map size is too much insignificant compared to the immense size of electric loads that inserting in this diagram at the NUST.

Fig. 7 (Appendix 12) depicts the total Electrical Load Served in kilowatt data on a random date throughout the months. It represents

Fig. 4. – A small community (university), Islamabad satellite view.

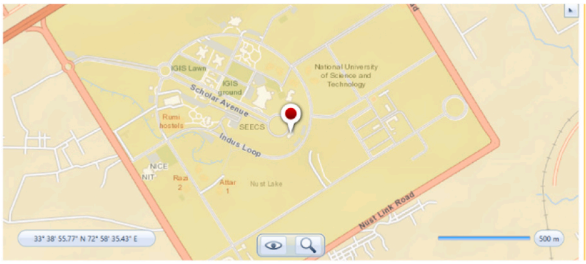


Fig. 5. Homer pro software location.

Table 1
Pakistan percentage rate per present.

Function	Value
Discount Rate (%)	22.00
Inflation Rate (%)	23.06
Annual Capacity Shortage (%)	1.00
Project Lifetime (Years)	25.00

Table 2
Electric load Kilo-Watts in January.

Hour	Electric Load (kW) - January
0	0.131
1	0.114
2	0.114
3	0.114
4	0.392
5	0.600
6	0.660
7	0.600
8	0.504
9	0.516
10	0.594
11	0.640
12	0.829
13	0.623
14	0.502
15	0.476
16	0.491
17	0.790
18	1.477
19	1.204
20	0.811
21	0.576
22	0.360
23	0.245

plot points showing kilowatts wherever the user decides to measure throughout the month. According to the Fig. 11, January to April and November to December (Winter Season) show significantly higher scaled kilowatts compared to other months, which fall within a lower range. Fig. 8 (Appendix 13 below) displays the whisker box measures for average scaled kilowatts in electricity units. According to Fig. 7 and Appendix 22, January and November have the largest set of box measurements (Q1, Median, Q3, minimum, and maximum of kilowatts). Whereas June and July are showing the lowest values for the whisker box values.

Fig. 9 (Appendix 14) illustrates the scaled load kW in graphical form for each month. In all 12 graphical plots, the highest peak values occur at 6 o'clock in the evening, while the lowest values are observed between 12 midnight and 3 a.m. This diagram clearly shows that the electric load reaches its maximum numerical value at 18 h every month.

The schematic diagram via HOMER Software is depicted in Fig. 12. The generator block is necessary because the renewable system is not fully equipped to meet 100 % of the energy demand. Despite the need for conventional energy, solar and wind blocks are in demand to reduce fossil fuel usage and limit carbon dioxide emissions. The generator and wind sectors produce AC current, while the output from solar PV cells is DC (Direct Current) current. Both types of current are stored in the storage sector as DC current input. The AC current needs to be converted to DC current by rectifiers before being stored in the storage area. Financial calculations related to electricity demand are also included in the diagram.

Table 3
Electric load annually.

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0.131	0.128	0.120	0.109	0.098	0.090	0.087	0.090	0.098	0.109	0.120	0.128
1	0.114	0.111	0.105	0.095	0.085	0.079	0.076	0.079	0.085	0.095	0.105	0.111
2	0.114	0.111	0.105	0.095	0.085	0.079	0.076	0.079	0.085	0.095.	0.105	0.111
3	0.114	0.111	0.105	0.095	0.085	0.079	0.076	0.079	0.085	0.095	0.105	0.111
4	0.392	0.383	0.360	0.327	0.294	0.271	0.262	0.271	0.294	0.327	0.360	0.383
5	0.600	0.585	0.550	0.500	0.450	0.415	0.400	0.415	0.450	0.500	0.550	0.585
6	0.660	0.644	0.605	0.550	0.495	0.457	0.440	0.457	0.495	0.550	0.605	0.644
7	0.600	0.585	0.550	0.500	0.450	0.415	0.400	0.415	0.450	0.500	0.550	0.585
8	0.504	0.541	0.508	0.462	0.416	0.383	0.370	0.383	0.416	0.462	0.508	0.541
9	0.516	0.553	0.520	0.473	0.426	0.393	0.378	0.393	0.426	0.473	0.520	0.553
10	0.594	0.637	0.599	0.545	0.490	0.452	0.436	0.452	0.490	0.545	0.599	0.637
11	0.640	0.686	0.645	0.586	0.528	0.487	0.469	0.487	0.528	0.586	0.645	0.686
12	0.829	0.889	0.836	0.760	0.684	0.631	0.608	0.631	0.684	0.760	0.836	0.889
13	0.623	0.668	0.628	0.571	0.514	0.474	0.457	0.474	0.514	0.571	0.628	0.668
14	0.502	0.538	0.506	0.460	0.414	0.382	0.368	0.382	0.414	0.460	0.506	0.538
15	0.476	0.511	0.480	0.437	0.393	0.362	0.349	0.362	0.393	0.437	0.480	0.511
16	0.491	0.526	0.495	0.450	0.405	0.373	0.360	0.373	0.405	0.450	0.495	0.526
17	0.790	0.770	0.724	0.658	0.592	0.546	0.526	0.546	0.592	0.658	0.724	0.770
18	1.477	1.440	1.354	1.231	1.108	1.022	0.985	1.022	1.108	1.231	1.354	1.440
19	1.204	1.174	1.103	1.003	0.903	0.832	0.802	0.832	0.903	1.003	1.103	1.174
20	0.811	0.791	0.744	0.676	0.608	0.561	0.541	0.561	0.608	0.676	0.744	0.791
21	0.576	0.562	0.528	0.480	0.432	0.398	0.384	0.398	0.432	0.480	0.528	0.562
22	0.360	0.351	0.330	0.300	0.270	0.249	0.240	0.249	0.270	0.300	0.330	0.351
23	0.245	0.239	0.224	0.204	0.184	0.169	0.163	0.169	0.184	0.204	0.224	0.239

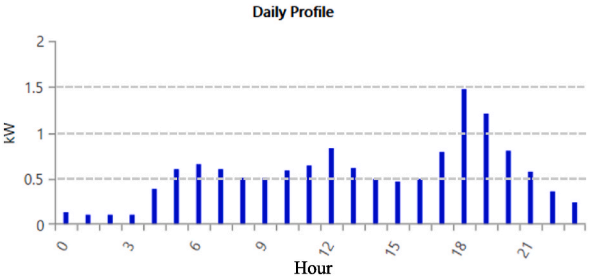


Fig. 6. Electric load bar chart.

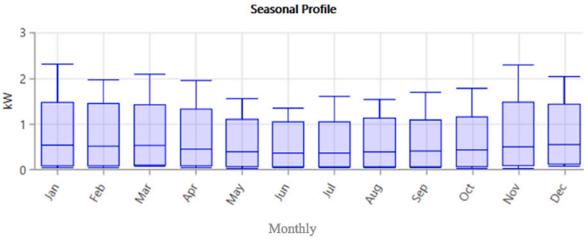


Fig. 7. Whisker plot.

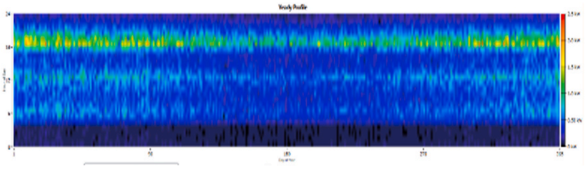


Fig. 8. Electric load visualization map.

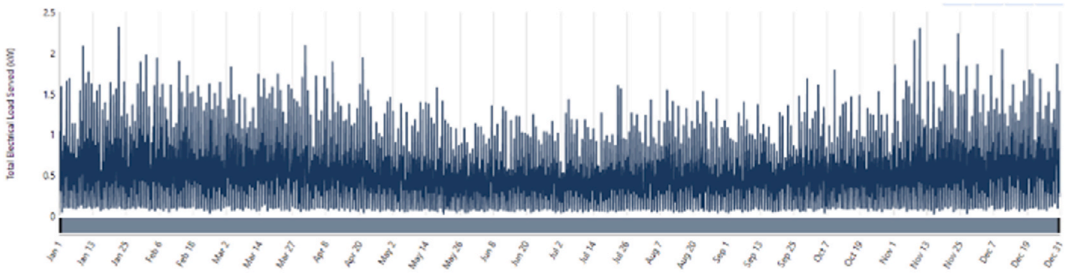


Fig. 9. Scaled electric load plotting.

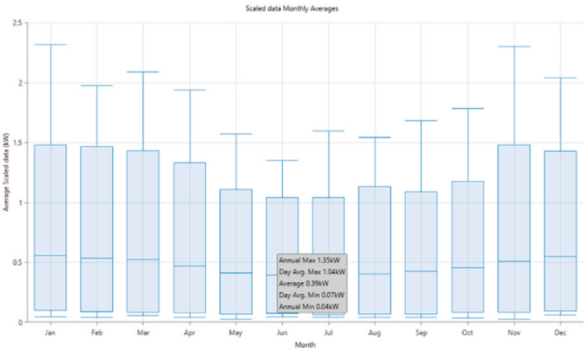


Fig. 10. Whisker box data for average KW versus monthly.

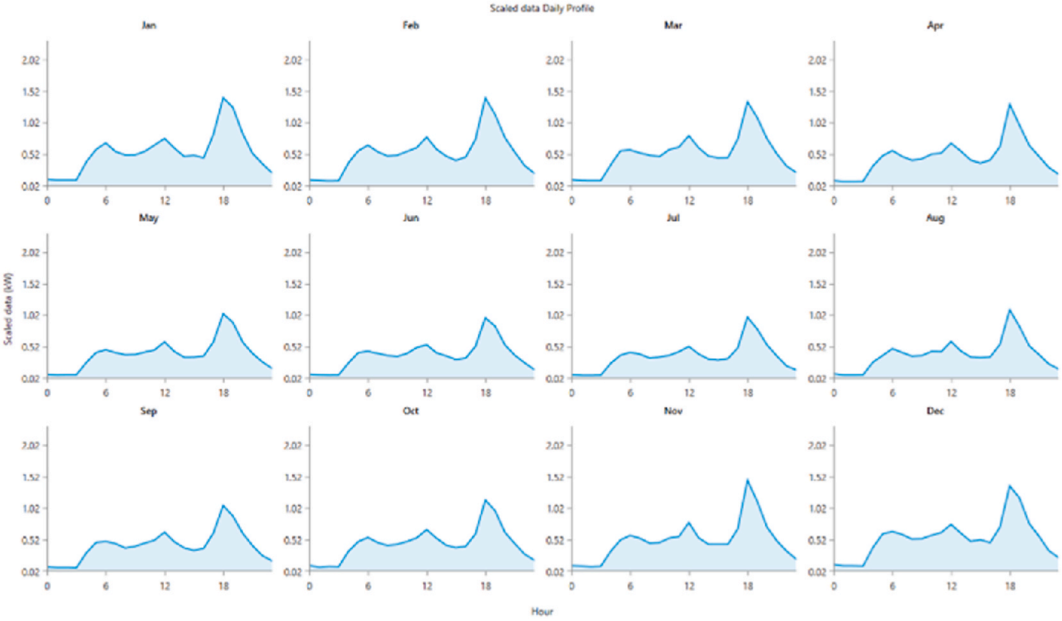


Fig. 11. Graphical data (scaled KW).

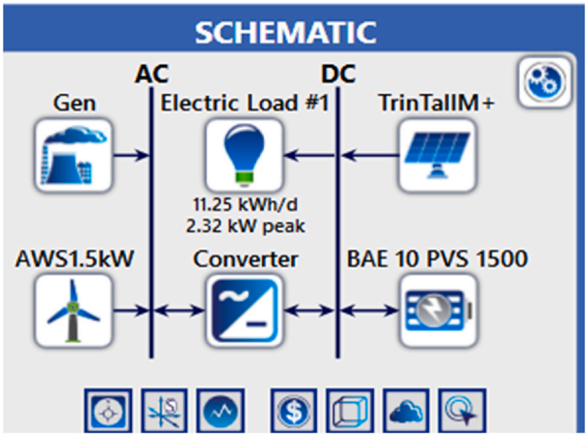


Fig. 12. Schematic diagram.

Table 4
Converter components.

Component	Min Qty	Max Qty	Bus
Generator	0	20	AC or DC
Storage	0	10	DC
PV	0	10	AC or DC
Wind Turbine	0	2	AC or DC
Converter	0	1	AC or DC
Boiler	0	1	Thermal
Hydroelectric	0	1	AC or DC
Hydrokinetic	0	1	AC or DC
Reformer	0	1	Hydrogen
Electrolyzer	0	1	AC or DC
HydrogenTan	0	1	Hydrogen
Grid	0	1	AC
Thermal Load	0	1	AC

Table 5
Converter controller details.

Converter Cost	
Capacitor (kW)	1
Capital (US$)	38.79
Replacement (US$)	28.02
Operational and Maintenance (US$)	0
Inverter Input	
Lifetime (Years)	15
Efficiency (%)	95
Rectifier Input	
Relative Capacity (%)	100
Efficiency (%)	95
Controller Time (Years)	25

The converter plays a vital role in handling both AC and DC currents as its main parameters. It processes components that produce either AC or DC energy output. According to HOMER Software, some of these components are in Table 4. Other functions that correspond to the converter are in Table 5.

The generator for this schematic diagram's model is autosize Genset, run by diesel (Artic) fuel. Table 6 displays the functions and values for Autosize Genset generator.

The graph 1 (Appendix 15) and graph 2 (Appendix 16) show the generator fuel (Artic Diesel) lines for fuel consumption (Litres/ Hours) and the fuel efficiency (%) respectively.

Graph 1 displays a straightforward positive trend, with the Y-axis intercept at approximately 0.16 L per hour based on the fuel consumption range. As the power output from conventional energy (fossil fuel production) increases, the fuel consumption in litres per

Table 6
Generator autosize genset details.

Function	Values
Fuel	Artic Diesel
Diesel Fuel Price (US$/L)	13.91
Lower Heating Value (MJ/kg):	43.20
Carbon Content (%):	88.00
Density (kg/m^3):	820.00
Sulfur Content (%):	0.40
Fuel curve intercept	0.165 L/h
Fuel curve slope	0.251 L/h/kW
Emissions	
CO (g/L fuel)	16.5
Unburned HC (g/L fuel)	0.72
Particulates (g/L fuel)	0.1
Fuel Sulfur to PM (%)	2.2
NOx (g/L fuel)	15.5
Fuel Properties	
Lower Heating Value (MJ/kg)	43.2
Density (kg/m3)	820
Carbon Content (%)	88
Sulfur Content (%)	0.4
Generator Cost per capacitor kW	
Initial Capital	US$ 84.90
Replacement	US$ 59.50
Operational and Maintenance	US$ 0.00
Generator Specific	
Minimum Load Ratio (%):	25.00
Heat Recovery Ratio (%):	0.00
Lifetime (Hours):	40000
Minimum Runtime (Minutes):	0.00

Table 7
Wind Speed versus Power Output kilowatts Curve.

Wind Speed (m/s)	Power Output (kW)
2.2	0.02
2.7	0.05
3.1	0.08
3.6	0.12
4	0.18
4.4	0.34
5.1	0.56
5.6	0.67
6	0.75
6.3	0.83
6.9	0.92
7.6	0.96
8	0.99
8.4	1.04
9	1.43
9.6	1.54
10.2	1.75
11	2.10
11.4	2.15
12	2.45

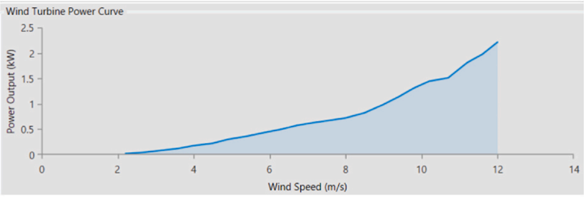


Fig. 13. Wind power output graph.

Table 8
Wind turbine details.

Function	Values
Capital Cost (US$)	3232.67
Replacement Cost (US$)	2514.30
Operational and Maintenance Cost (US$)	64.65
Lifetime (Years)	20
Hub Height (m)	8

hour gradually rises. In Graph 2, the fuel usage efficiency percentage begins at the origin (0, 0). As the power output from conventional energy appliances steadily increases from 0 to roughly 0.7 kW, the Y-axis shows a moderate bend from 0 to 20 percent. Subsequently, this bend transitions to a near-straight increase from 20 to approximately 33 percent as the power output rises from 0.7 to around 2.7 kW. Consequently, the litres per hour required for the power unit represents an average energy cost. However, this value could be reduced when renewable energies within the microgrid system are activated.

The first renewable energy that producing energy to the University, Islamabad is the Wind Power Source. Although, there are no major components, the university has small wind farms yet effective efficiency. These miniature wind powers can ultimately produce the AC current and store it into the storage cells afterwards. Thus, the wind power model is AWS HC 1.5 kW Wind Power source which stands at the height of 8 m. Other functions of this wind power are in Table 7.

The graph for the wind rotor is clearly depicted the curve shape with the power output (kW) and the wind speed (m/s) (see Fig. 12). As the wind speed increases, the power output has also increased much faster too. Fig. 13 is corresponding to appendix 17.

According to wind turbine analyses, the data between the wind speed and the power output has shown in Table 8. The initial wind speed, according to Tables 8 and is 2.2 m per second. This value is reflected in Fig. 3 (Wind Power Output), particularly during the early morning hours (12 a.m.–6 a.m. daily) and continues to increase to the maximum wind speed ratings. Typically, as the wind speed increases to 2.7 m/s, 3.1 m/s, and 3.6 m/s up to 12 m/s, the wind power output substantially rises from 0.05 kW, 0.08 kW, and 0.12 kW–2.45 kW respectively. Although many regions in Pakistan provide higher wind speeds and consequently higher power output, the University community in Islamabad can benefit from this microgrid system by merging this specific wind power output with solar PV and generators.

The second renewable energy source for the university is the solar photovoltaic (PV) cell equipment. This technology harnesses energy from the Sun's rays, with peak energy conversion typically occurring from around 11 a.m. until sunset. The university utilizes the Trina Tallmax M Plus model (Table 9) to gather solar renewable energy data such as solar irradiance factors for analysis using software.

Once both renewable energy sectors generate power output, it can be readily used for various applications such as air conditioning, heaters, and fans. Any excess power output can be sold to the government or other customers through the electricity grid. Alternatively, excess energy can be stored in storage areas. While storing electricity presents challenges and incurs inflated costs, it proves invaluable during disturbances such as electricity blackouts. The storage sector, essentially acting as a battery, stores electricity for later use, providing supply to other areas as needed. The university, Islamabad employs the BAE Secura Solar 10 PVS 1500 (kinetic battery) model for this purpose. The properties and calculations of this model are detailed in Table 10.

The final results for this software regarding the costs for the University in Islamabad encompass both conventional and renewable energy power outputs. It is important to note that the calculations in this Master Research thesis may vary from other facts due to the inclusion of numerous parameters in energy optimization. The results are presented alongside sensitive and optimization cases. The optimization case involves further simulation of renewable energy at the location. Details of the sensitive and optimization cases can be found in Table 17-Sensitive Case Results and Table 16-Optimization Case Results (Appendix 2 and Appendix 1). respectively.

The simulation results for the hybrid microgrid, containing the solar PV and Wind power are display with cost of renewable energy electricity. A few of costs are mentioned in Table 11.

Table 9
Trina tallmax PV details.

Function	Values
Panel Type	Flat Plate
Rated Capacity (kW)	0.345
Material Module	Monocrystalline 72 cell
Power Output Rated (W)	325–345 (0.325–0.345 kW)
Efficiency Maximum (%)	17.8
PV Cost	
Capacity (kW)	1
Capital (US$))	145.83
Replacement (US$)	0
Operational and Maintenance (US$)	1.46
Lifetime (Years)	25
MPPT Lifetime (Years)	15
Ground Reflectance (%)	20
Tracking System	Horizontal Axis (Monthly Adjustment)

Table 10
Kinetic batterien GmbH details.

Function	Values
Nominal Voltage (V)	2
Nominal Capacity (kWh)	2.67
Maximum Capacity (Ah)	1.33E+03
Capacity Ratio	0.15
Rate Constant (1/hr)	4.23
Roundtrip efficiency (%)	95
Maximum Charge Current (A)	452
Maximum Discharge Current (A)	1.52E+03
Maximum Charge Rate (A/Ah)	1
Kinetic Battery Cost	
Capital (US$)	55000
Replacement (US$)	50120
Operational and Maintenance (US$)	0
Lifetime	
Throughput (kWh)	3043.20
Time (Years)	6
Kinetic Battery Input	
String Size (Factor)	6
Total Voltage (Factor * Nominal Voltage)	12 V
Initial State of Charge (%)	100
Minimum State of Charge (%)	20

Table 11
Simulation result 1.

Total NPC:	US$ 233678.34
Levelized COE:	US$ 2.03
Operating Cost:	US$ 8132.06

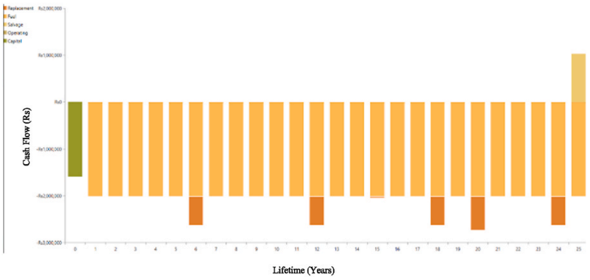


Fig. 14. Investment sectors.

Fig. 14 (Appendix 18) shows the cash flow for the University community, Islamabad over the lifetime of both renewable and conventional energy (microgrid hybrid system) in years. The cash flow over a 25-year period for the hybrid microgrid renewable plant in this University community encompasses replacement, fuel, salvage, operating, and capital costs. Each cost category is signified by a distinct colour for easy identification and interpretation. All financial costs, except for the salvage character, are presented as downward-bars, indicating cash outflow for the energy expenses. On the contrary, the upward bars represent the salvage cost in the end of lifetime 25 years, indicating income generated from sales for these certain microgrid grid's components. The cash flow for the initial year (year 0) includes the capital investment for the small community's renewable and conventional energy systems, with

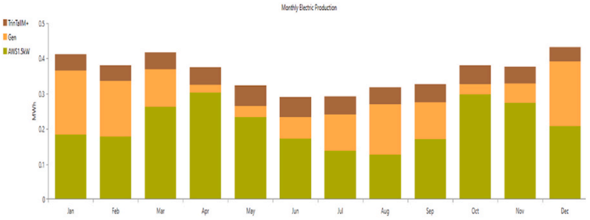


Fig. 15. Electric production.

stakeholders expected to invest approximately Rs. 1,600,000 (US$ 5743.46) initially. The fossil fuel-powered Autosize Genset generator incurs consistent expenses over 25 years, while integrating renewable energy helps reduce the carbon footprint. Replacement costs occur in three sets of six-year intervals during the first 18 years, each costing approximately Rs. 2,500,000 (US$ 8974.15) in years 6, 12, and 18. Additional replacement expenses will be required in Years 20 and 24. At the end of the 25-year period, the salvage value of the energy investment will yield a profit of exactly Rs. 1,000,000 (US$ 3589.66) for the stakeholders.

Appendix 19 (Table 19: Energy Costs) details the energy costs for NUST, highlighting values for both conventional and renewable energy sources. The AutoGen generator's capital, replacement, operational, and maintenance costs in US dollars are lower compared to the more expensive wind power, Solar PVs, controllers, converters, and storage cells. However, renewable energy sources have zero fuel costs and hence no greenhouse gas emissions. On the contrary, generators require significant fuel, emitting toxic gases. The microgrid system aims to balance these energy sources, making annual costs ideal for reducing emissions and enhancing machinery efficiency with proper tools.

Fig. 15 (Appendix 20) displays the Energy cost in microgrid hybrid system. This energy costs recalling from table 18 indicate that the generator's energy production has significantly higher financial implications compared to renewable energy sourced from solar PVs and wind power. Despite the continuous energy generation from renewable sources, this factor of conventional energy (autosize generator component) remains as the primary source of electricity. Transitioning to renewable energy sources could substantially reduce both the consumption and costs associated with conventional fuel electricity production while also helping to reduce greenhouse gas emissions.

Fig. 16 (Appendix 21) highlights the electric production of renewable power output, displaying kilowatts versus monthly blocks. According to this diagram, wind power output exhibits the highest electricity output compared to the generator and solar PV cells at the University. Solar PV cells also contribute to the renewable energy stock, although to a lesser extent, which may present challenges. Nonetheless, all three power outputs play a crucial role in achieving higher efficiency of renewable and conventional energy at that location. The data for this case is shown in Table 12.

Fig. 17 (Appendix 22) illustrates the conventional energy fossil fuel consumption in the university community. According to the diagram from the HOMER software, the highest whisker boxplot values occur in January, February, July, August, September, and December, with approximately 0.35, 0.34, 0.29, 0.32, 0.3, and 0.35 L per hour, respectively Fig. 10, Appendix 10 and Appendix 13. On the contrary, the lowest whisker boxplot values are in April, May, June, and October, with roughly 0.06, 0.11, 0.15, and 0.09 L per hour. The remaining months (March and November) show medium whisker boxplot values at approximately 0.25 and 0.19 L per hour. Thus, the lowest months likely seems more renewable energy production due to the summer and windy seasons, compared to the highest whisker boxplot months.

Figs. 18 and 19 illustrate the conventional fuel consumption, specifically Arctic Diesel liquid and its generator output chart, in the progress of the University. The whisker plots (Fig. 17) diagram depicts the behaviour when diesel fuel is being used in these Figs. 18 and 19's figures.

Fig. 18 (Appendix 23) clearly delineates fuel consumption per month. During months prioritized for renewable energy usage, such as those mentioned earlier, there is no fuel consumption (see Fig. 18) for these applications compared to the remaining months. Fuel consumption occurs from January to March, decreases from March to June, then rises again from June to September. Subsequently, there is a decrease in fuel consumption from September to October, followed by an increase from October to December. Higher fuel consumption occurs in the evening (after 6 p.m.) compared to daytime due to the increased reliance on fossil fuels.

Fig. 19 (Appendix 24) illustrates the generator power output charts over the months. Approximately from days 90–160 and days 270–300, there is no generator power output, indicating lower conventional fuel consumption due to the utilization of renewable energy. This behaviour is similar to the pattern observed in Fig. 18 regarding fuel consumption usage. Table 13 complements the generator power output charts by providing detailed information on electrical production, including minimum, median, and maximum values, as well as fuel consumption specifications.

Figs. 20–22 (Appendices 25, 26, and 27 respectively) display the renewable penetration for this hybrid microgrid. Fig. 20 illustrates a lower amount of renewable energy when divided by the load electricity. However, Figs. 21 and 22 show instances of renewable energy when divided by the generation and non-renewable instantaneous factor. These three diagrams represent complex mathematical results but can be compared with the fuel consumption and electric data diagrams. This comparison aligns with the renewable energy factors within the university community. Table 14 compiles the renewable penetration data factor.

Finally, addressing emissions of carbon dioxide and other harmful gases poses a challenge in optimizing this hybrid microgrid evaluations. However, these toxic gases can be effectively controlled by utilizing the output electricity from renewable energy sources most of the time. Table 15 outlines the emission behaviors and control scheme.

According to Ullah et al., the optimization (Appendix 1) is performed to obtain the low-cost optimal system while providing different feasible configurations. This optimization is based on the total net present cost (TNPC), initial capital cost, operation and

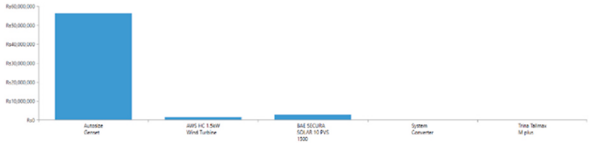


Fig. 16. Community investment sectors.

Table 12
Electric production data.

Function	kWh/year	%
Production		
Autosize Genset	1185	27.4
AWS HC 1.5 kW Wind Turbine	2546	58.8
Trina Tallmax M Plus	596	13.8
Total Production Cost	4327	100
Consumption		
AC Primary Load	0	0
DC Primary Load	4105	100
Total Consumption Cost	4105	100
Quantity		
Excess Electricity	0.0228	0.000500
Unmet Electric Load	0	0
Capacity Shortage	0	0
Quantity	**Value**	
Renewable Fraction	71.1	
Maximum Renewable Penetration	2144	

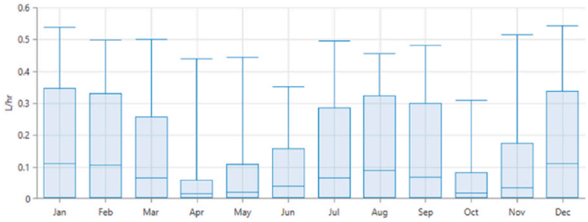


Fig. 17. Diesel whisker plot.

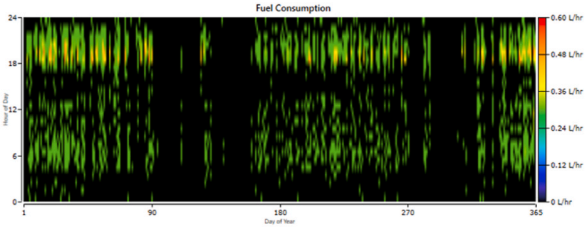


Fig. 18. Fuel consumption chart.

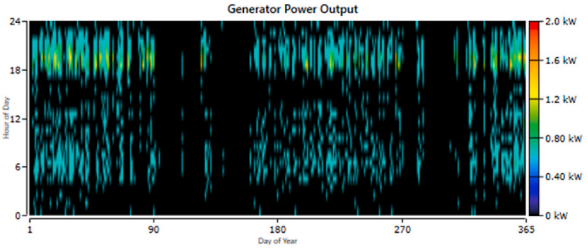


Fig. 19. Generator power output chart.

maintenance (O&M) cost and cost of energy (COE). The TNPC is the outline of the present value of all cash-out flow including initial capital, O&M, replacement, and fuel cost minus the summation of all the cash-inflows (salvage) of the system throughout its lifetime. This medic of cash flow is like the cash flow in this research manuscript [2].

So, these figures and tables at NUST should have lower values when using the renewable energy resources (Solar PVs and Wind Power) as well as the balance with conventional energy in this microgrid hybrid system. These outputs could be incredibly low or else extremely high depending on ideal resultants. If these values are adequate, then this methodology could be used in South and South-

Table 13
Generator data.

Quantity	Value	Units
Hours of Operation	1665	Hours/Year
Number of Starts	823	Starts/Year
Operational Life	24	Year
Capacity Factor	5.01	%
Fixed Generation Cost	623	Rs/Hour
Marginal Generation Cost	950	Rs/kWh
Electrical Production	1185	kWh/Year
Mean Electrical Output (Q2)	0.712	kW
Minimum Electrical Output	0.675	kW
Maximum Electrical Output	1.66	kW
Fuel Consumption	572	Litres
Specific Fuel Consumption	0.483	Litres/kWh
Fuel Energy Input	5628	kWh/Year
Mean Electrical Efficiency	21.0	%

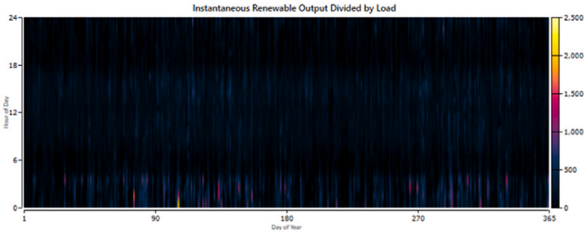


Fig. 20. Renewable Energy divided Electric Load.

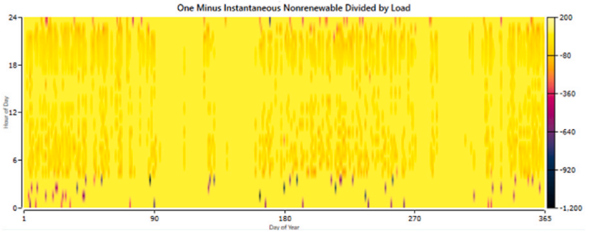


Fig. 21. Instantaneous Conventional divided load.

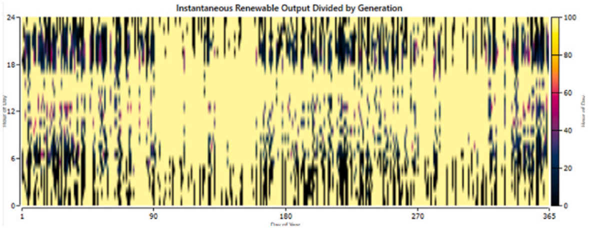
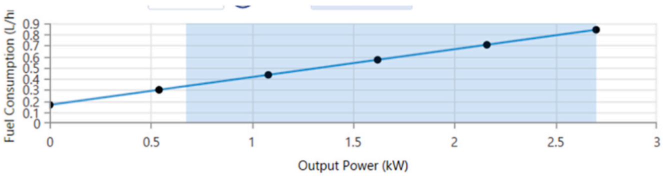
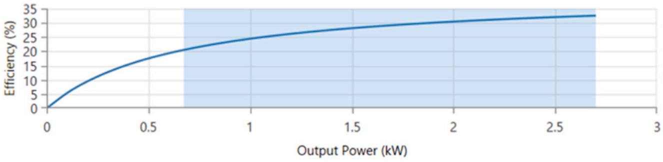


Fig. 22. Renewable Output divided Generator.



Graph 1. Fuel consumption (litres per hours).



Graph 2. Fuel usage efficiency (%).

Table 14
Renewable penetration data.

Function	Value	Units
Peak Values		
Renewable Output Divided by Load (HOMER Standard)	2144	%
Renewable Output Divided by Total Generation	100	%
One Minus non-renewable output divided by total load	100	%
Capacity Based Metric		
Nominal Renewable Capacity divided by Total Nominal Capacity	40.6	%
Useable Renewable Capacity divided by Total Capacity	48	%
Energy Based Metric		
Total Renewable Production divided by Load	76.5	%
Total Renewable Production divided by Generation	72.6	%
One Minus total non-renewable production divided by load	71.1	%

Table 15
Emission data.

Quantity	Values	Units
Carbon Dioxide	1497	Kg/year
Carbon Monoxide	9.44	Kg/year
Unburned Hydrocarbons	0.412	Kg/year
Particulate Matter	0.0572	Kg/year
Sulfur Dioxide	3.67	Kg/year
Nitrogen Oxides	8.87	Kg/year

East countries as their developing infrastructures. Moreover, it could be corporate with developed nations for optimization these conventional and renewable energies.

According to the HOMER software, Appendix 28 presents the cost expenses associated with renewable and conventional energy for a small community (NUST), focusing on the net present cost (NPC) and initial capital cost in USD. The NPC represents the present value of all costs related to the renewable energy system over its lifetime (20–25 years) in this community. This includes capital costs, operations and maintenance costs, and fuel costs (for conventional energy), all discounted to their present value using the community's discount rate. For initial payments, investors and financial loans will fully cover these costs for both conventional and renewable energy's components. These payments will then be repaid to the contributors over the installation period, depending on these components' lifespan, as shown in Figs. 14, 16, Appendix 18 and Appendix 20.

If this community relies solely on conventional fossil fuel energy, the initial capital cost is US$ 59.4, while the NPC is US$ 1,085,834.69. However, when integrating renewable energy, the values change significantly. The initial capital cost is US$ 5771.88, and the NPC for producing electricity using both energy sources is US$ 218,970.65.

The initial cost for conventional energy is quite significantly lower compared to the combined initial costs of conventional and renewable energy, with an approximate ratio of 97:1; favouring fossil fuel for cheaper electricity production. However, the NPC for fossil fuels exceeds the cost compared to the NPC of the combined conventional and renewable energy sources. When considering the cost ratio, the combined renewable/conventional energy system is approximately five times cheaper than using conventional energy alone. Thus the combined energy is cheaper in NPC value instead of conventional fossil fuel provider The difference in NPC between these two components is USD 1,085,834.69–218,970.65 = US$ 866,864.04 in pointed of fossil fuels. This value also accounts for wasteful power units and carbon emissions costs towards the environment factors. Therefore, the microgrid hybrid system can balance these two factors to reduce the amount of toxic gases released into the environment by fossil fuel primary fuel only and also providing reliable power sources to the community. This balance can optimize the feasibility cost and environmental impact, ensuring a more sustainable energy solution.

4. Conclusions

The feasibility analysis of this hybrid microgrid at the NUST, Islamabad demonstrates sustainable efforts aimed at reducing emissions while effectively advancing renewable energy production. However, it is essential to balance the utilization of conventional energy, derived from fossil fuels, with renewable energy sources. This balance is crucial to mitigate the risks associated with relying solely on renewable energy for continuous operation without interruptions. The evaluations conducted by HOMER software suggest focusing on optimizing the utilization of wind power and solar PV cells while forecasting their performance for future periods through simulation. Although precise data may not always be available to refine renewable energy output predictions, this software provides estimations that contribute to effective microgrid planning and management.

The hybrid microgrid project not only for Pakistan but South and South-East of Asia and other nations marks a major advancement in sustainable energy rather than dominated in conventional energy. By harnessing renewable energy sources and optimizing their use, this initiative of the microgrid hybrid aims to reduce reliance on conventional energy, lower emissions, and enhance energy resilience. The insights gained from these feasibility analyses offer an economic evaluation, providing valuable guidance for the future renewable energy projects, both within this community and beyond nations as well. This approach not only fosters a cleaner, plantation for absorb and greener future times in terms of gasses but also sets a precedent factor for this sustainable energy development in other regions.

CRediT authorship contribution statement

Ahmed Shabbir Moomin: Writing – review & editing, Writing – original draft, Data curation. **Muhammad Yousif:** Writing – review & editing, Validation, Supervision. **Hassan Abdullah Khalid:** Supervision, Software, Conceptualization. **Syed Ali Abbas Kazmi:** Visualization, Software, Methodology, Data curation. **Thamer A.H. Alghamdi:** Writing – review & editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Appendix 1
Optimization Case Results

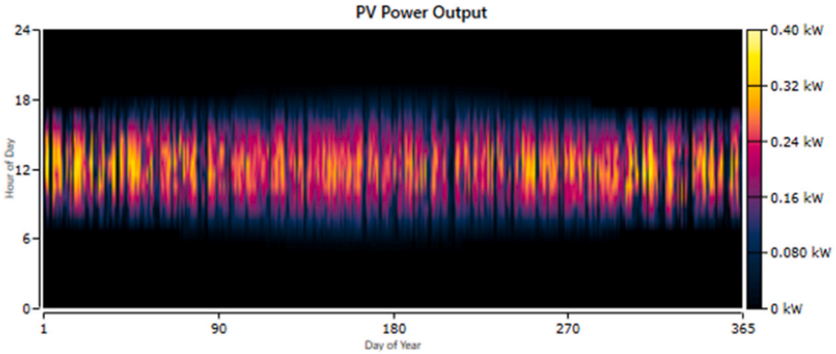
Architecture											Cost				System		Generator					TrinTallM +		AWS 1.5 kW			BAE 10 PVS 1500				Converter	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1	2	3	4	5	0.345	1	2.70	12	2.07	LF	565.37	65.1	2.26	1.60	71.1	572	1665	1185	572	2.05	2.16	14	596	0.9	2546	18	54.6	1185	32.0	25.6	0.405	0
	2	3	4	5		1	2.70	6	2.06	LF	841.69	96.9	3.41	1.25	55.1	885	2586	1827	885	3.18	3.35			0.9	2546	18	27.3	1096	16.0	12.8	0.474	0
1	2		4	5	0.345	1		534	1.69	LF	1097	125	3.39	30.3	100	0						14	596	0.9	2546	18	2430	1947	1947	1139	0.275	0
1		3	4	5	0.345		2.70	6	1.29	LF	1665	189	6.74	0.36	9.19	1773	5105	3708	1773	6.29	6.70	14	596				27.3	948	16.0	12.8	0.402	0
		3	4	5			2.70	6	1.33	LF	1932	221	7.87	0.34	0	2071	5971	4330	2071	7.35	7.84						27.3	852	16.0	12.8	0.470	0
1	2	3		5	0.345	1	2.70		1.46	LF	2522	289	10.3	0.93	0	2708	7947	5567	2708	9.78	10.2	14	596	0.9	2546	18					0.398	0
	2	3		5		1	2.70		1.46	LF	2539	291	10.3	0.92	0	2726	7992	5611	2726	9.84	10.3			0.9	2546	18					0.466	0
1		3		5	0.345		2.70		1.46	LF	2816	322	11.5	0.03	0	3039	8760	6353	3039	10.8	11.5	14	596								0.398	0
		3		5			2.70		1.46	LF	2829	324	11.6	0.02	0	3054	8760	8760	3054	10.8	11.6										0.466	0

Appendix 2

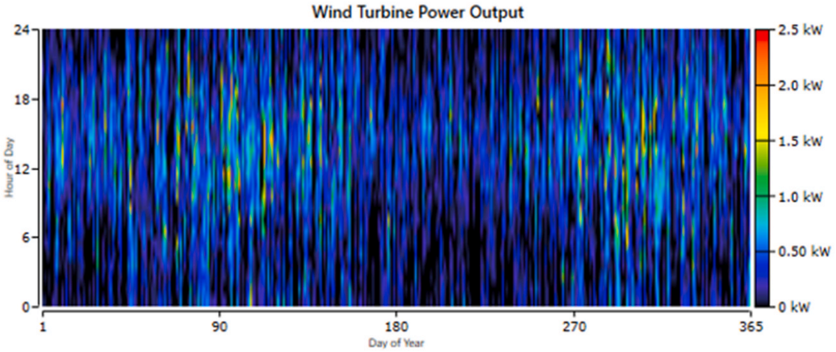
Sensitive Case Results

Architecture											Cost				System		Generator					TrinTallM+		AWS 1.5 kW			BAE 10 PVS 1500				Converter	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1	2	3	4	5	0.345	1	2.70	12	2.07	LF	565.37	65.1	2.26	1.60	71.1	572	1665	1185	572	2.05	2.16	14	596	0.9	2546	18	54.6	1185	32.0	25.6	0.405	0

1 – Solar PV Cell Sector.
2 – Wind Power Sector.
3 – Generator Sector.
4 – Storage Battery Cells Sector.
5 – Converter (AC<–>DC) Sector.
6 – Solar PV Trina Tallmax M Plus model.
7 – Wind Turbine AWS 1.5 kW model.
8 – Autosize Genset Generator kW.
9 – Kinetic Batterien GmbH BAE 10 PVS 1500.
10 – Generic System Converter model kW.
11 – Dispatch energy resources (LF – load factor).
12 – Cost of Energy (COE).
13 – Net Present Cost (NPC) – Million Rupees.
14 – Operating Cost (Million Rupees per Year).
15 – Initial Capital (Million Rupees).
16 – Renewable Fraction (%).
17 – Total Fuel (Liter per Year).
18 – Hours.
19 – Production (kWh).
20 – Fuel (Litres).
21 – Operational and Maintenance Cost (Rupees per Year).
22 – Fuel Cost (Million Rupees per Year).
23 – Capital Cost (Rupees x 1000).
24 – Production (kWh per Year).
25 – Capital Cost (Million Rupees).
26 – Production (kWh per Year).
27 – Operational and Maintenance Cost (Rupees x 1000).
28 – Autonomy (Hours).
29 – Annual Throughput (kWh per Year).
30 – Nominal Capacity (kWh).
31 – Useable Nominal Capacity (kWh).
32 – Rectifier Mean (kW).
33 – Inverter Mean Out (kW).



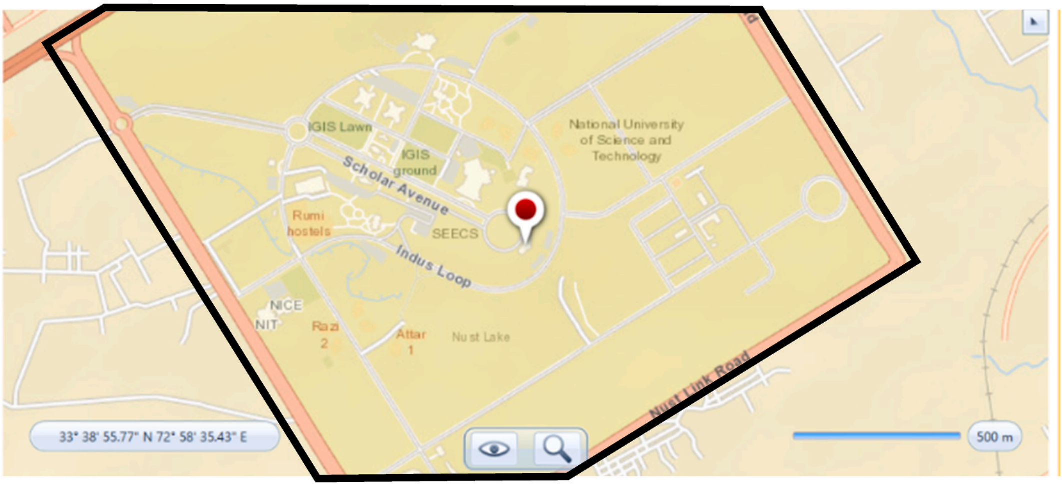
Appendix 3. Solar PV Power Output Chart



Appendix 4. Wind Turbine Power Output

Appendix 5. NUST (near USPCAS-E) Solar PV panels

Appendix 6. NUST's AEOLOS wind vertical vxis power turbine

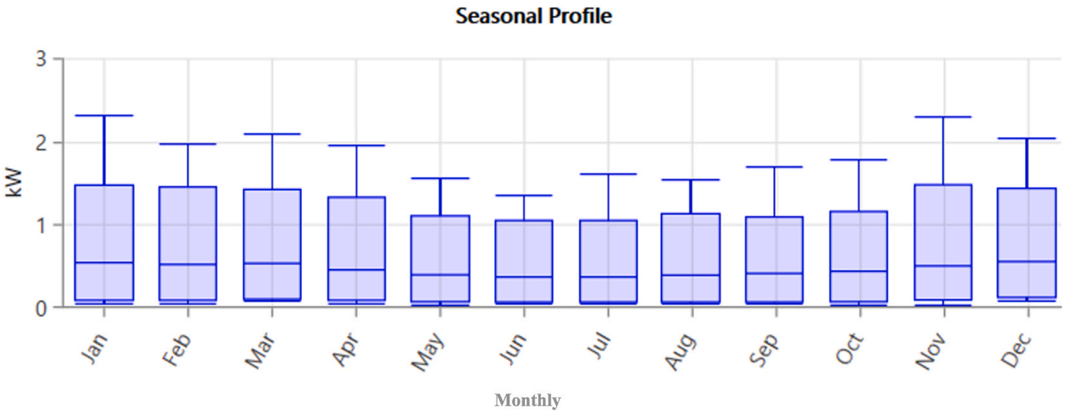


Appendix 7. Homer Pro Software Location

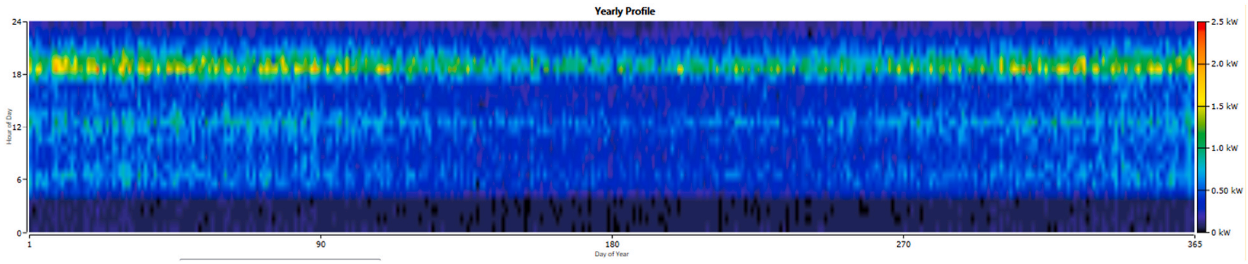
Appendix 8. A Small Community (University), Islamabad Satellite View

Appendix 9
Electric Load Annually

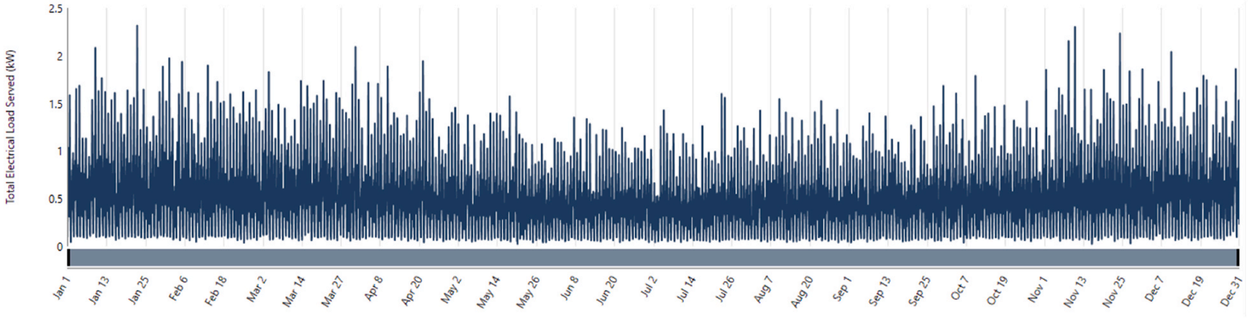
Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0.131	0.128	0.120	0.109	0.098	0.090	0.087	0.090	0.098	0.109	0.120	0.128
1	0.114	0.111	0.105	0.095	0.085	0.079	0.076	0.079	0.085	0.095	0.105	0.111
2	0.114	0.111	0.105	0.095	0.085	0.079	0.076	0.079	0.085	0.095.	0.105	0.111
3	0.114	0.111	0.105	0.095	0.085	0.079	0.076	0.079	0.085	0.095	0.105	0.111
4	0.392	0.383	0.360	0.327	0.294	0.271	0.262	0.271	0.294	0.327	0.360	0.383
5	0.600	0.585	0.550	0.500	0.450	0.415	0.400	0.415	0.450	0.500	0.550	0.585
6	0.660	0.644	0.605	0.550	0.495	0.457	0.440	0.457	0.495	0.550	0.605	0.644
7	0.600	0.585	0.550	0.500	0.450	0.415	0.400	0.415	0.450	0.500	0.550	0.585
8	0.504	0.541	0.508	0.462	0.416	0.383	0.370	0.383	0.416	0.462	0.508	0.541
9	0.516	0.553	0.520	0.473	0.426	0.393	0.378	0.393	0.426	0.473	0.520	0.553
10	0.594	0.637	0.599	0.545	0.490	0.452	0.436	0.452	0.490	0.545	0.599	0.637
11	0.640	0.686	0.645	0.586	0.528	0.487	0.469	0.487	0.528	0.586	0.645	0.686
12	0.829	0.889	0.836	0.760	0.684	0.631	0.608	0.631	0.684	0.760	0.836	0.889
13	0.623	0.668	0.628	0.571	0.514	0.474	0.457	0.474	0.514	0.571	0.628	0.668
14	0.502	0.538	0.506	0.460	0.414	0.382	0.368	0.382	0.414	0.460	0.506	0.538
15	0.476	0.511	0.480	0.437	0.393	0.362	0.349	0.362	0.393	0.437	0.480	0.511
16	0.491	0.526	0.495	0.450	0.405	0.373	0.360	0.373	0.405	0.450	0.495	0.526
17	0.790	0.770	0.724	0.658	0.592	0.546	0.526	0.546	0.592	0.658	0.724	0.770
18	1.477	1.440	1.354	1.231	1.108	1.022	0.985	1.022	1.108	1.231	1.354	1.440
19	1.204	1.174	1.103	1.003	0.903	0.832	0.802	0.832	0.903	1.003	1.103	1.174
20	0.811	0.791	0.744	0.676	0.608	0.561	0.541	0.561	0.608	0.676	0.744	0.791
21	0.576	0.562	0.528	0.480	0.432	0.398	0.384	0.398	0.432	0.480	0.528	0.562
22	0.360	0.351	0.330	0.300	0.270	0.249	0.240	0.249	0.270	0.300	0.330	0.351
23	0.245	0.239	0.224	0.204	0.184	0.169	0.163	0.169	0.184	0.204	0.224	0.239



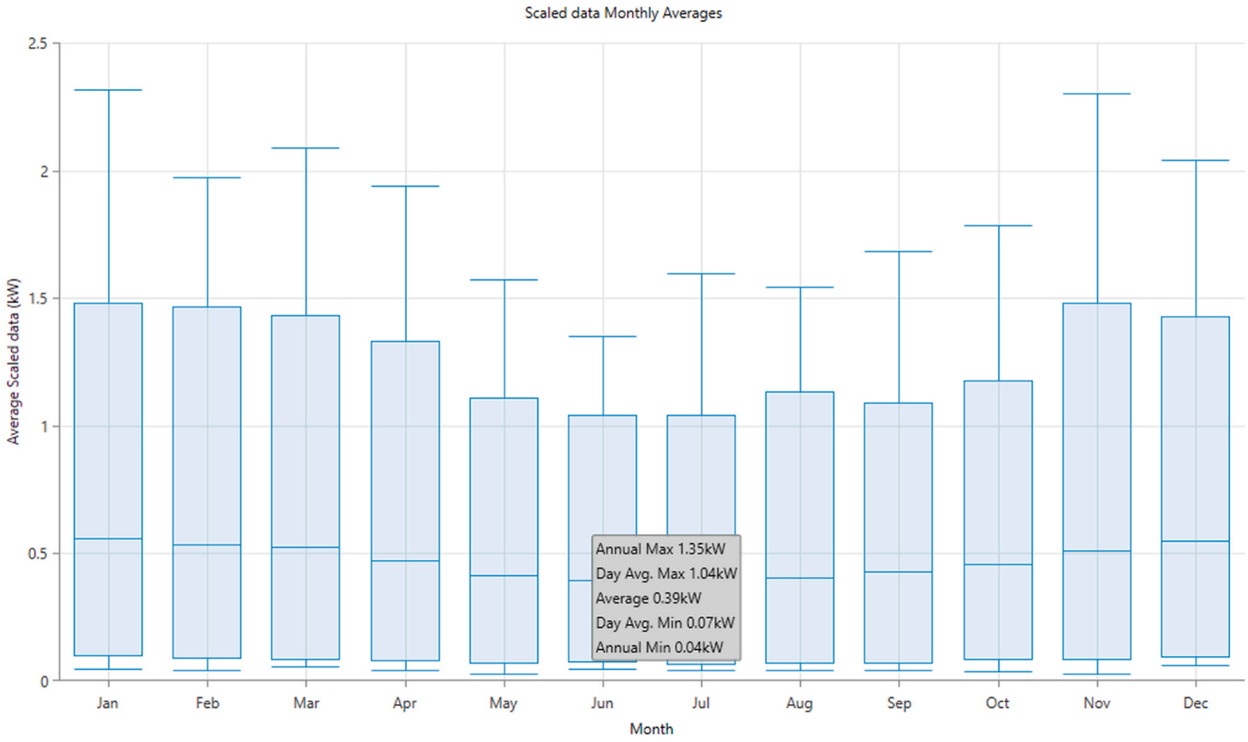
Appendix 10. Power Whisker Plot



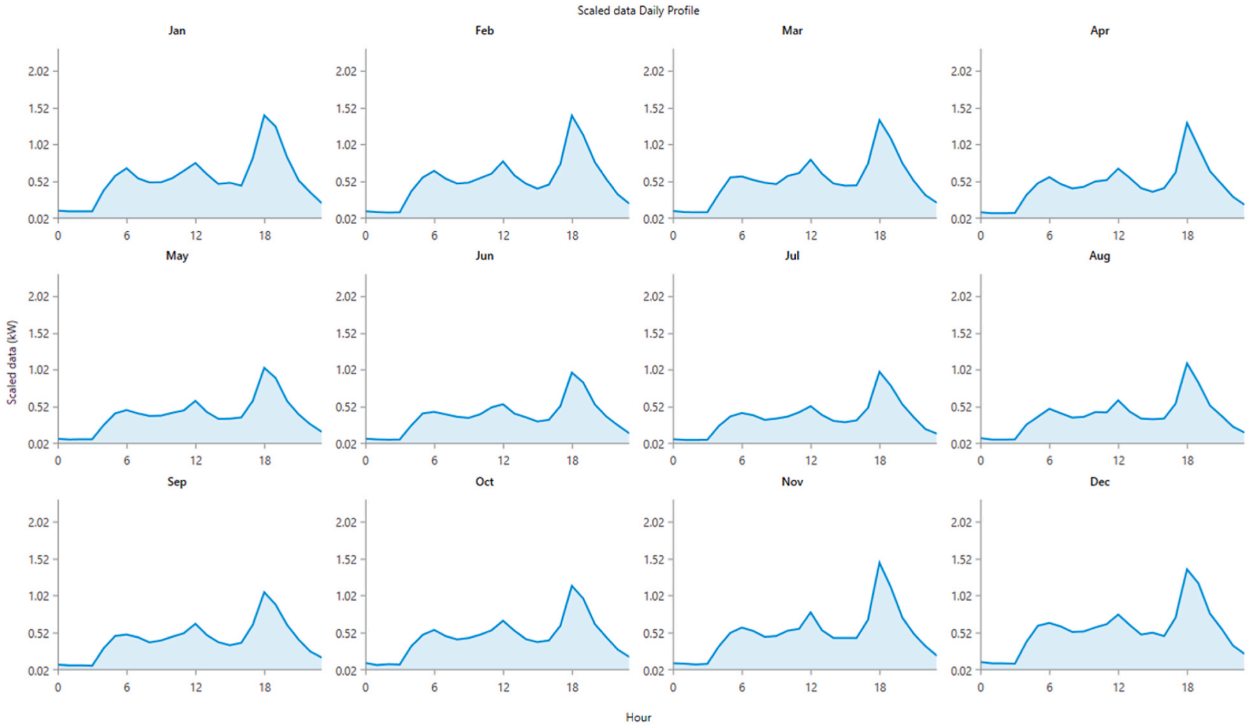
Appendix 11. Electric Load Visualization



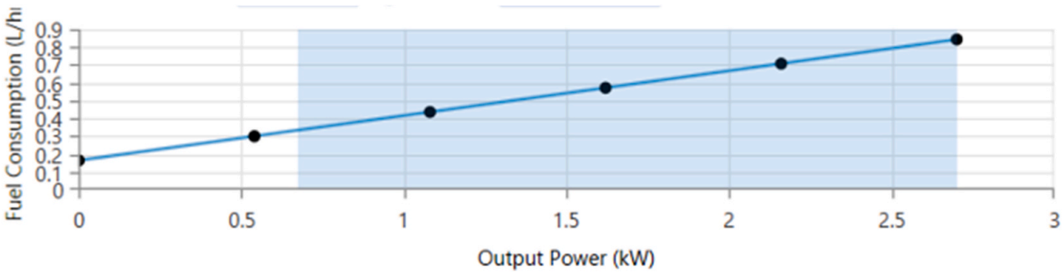
Appendix 12. Small Community Electrical Power Output



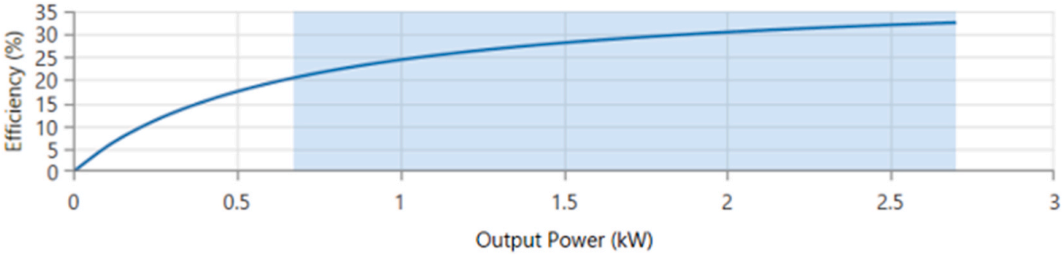
Appendix 13. Whisker Box Plot Electric Load



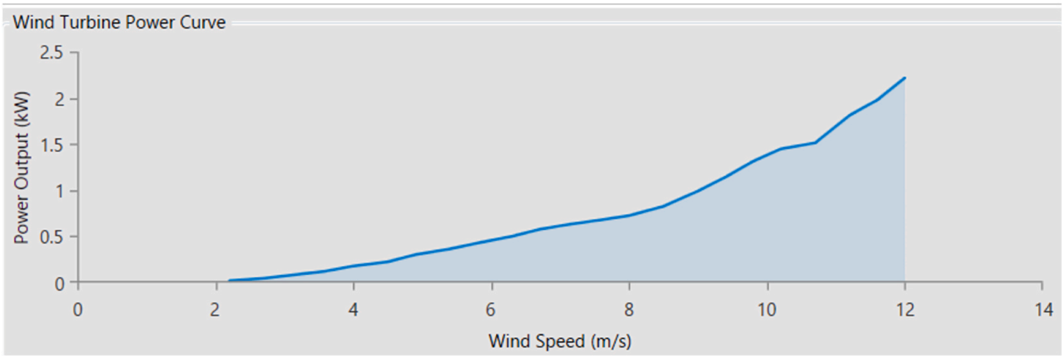
Appendix 14. Scaled Data Daily per Electric Load



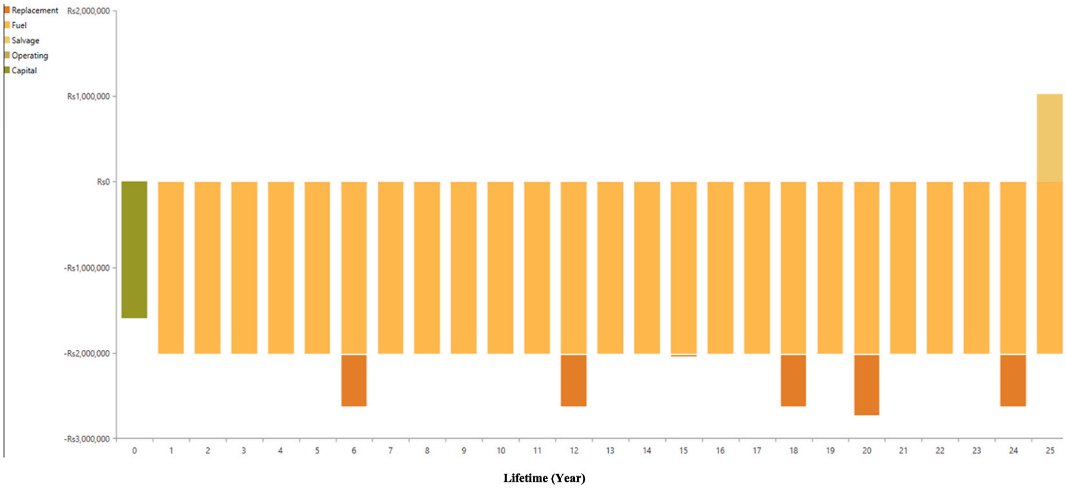
Appendix 15. Fuel Consumption (Litres per Hours)



Appendix 16. Fuel Usage Efficiency (%)



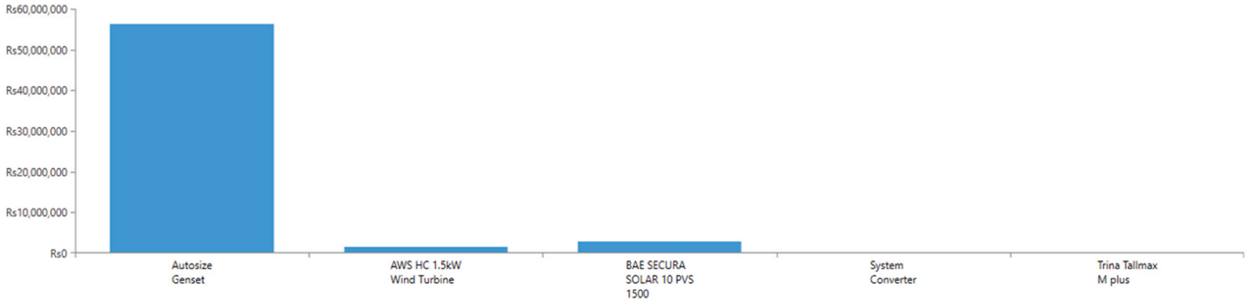
Appendix 17. Wind Power Output Graph



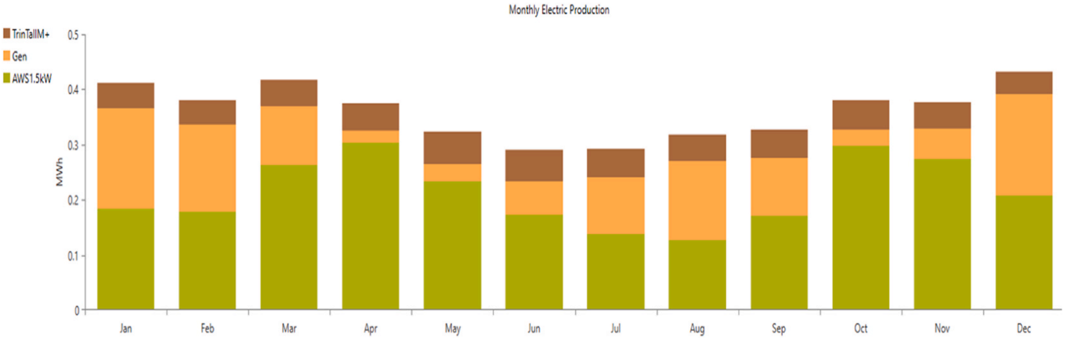
Appendix 18. Investment Sectors

Appendix 19
Energy Costs

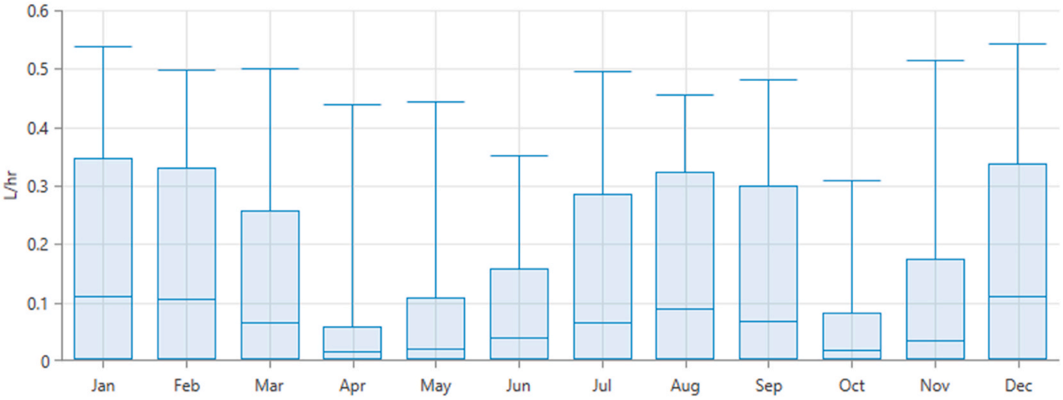
Component	Capital (US$)	Replacement (US$)	O & M (US$)	Fuel (US$)	Salvage (US$)	Total (US$)
Autosize Genset	0.82	0.71	0.21	218106.69	0.69	218107.75
AWS HC 1.5 kW Wind Turbine	3237.12	2993.34	1814.75	0.00	2344.24	5700.96
BAE SECURA SOLAR 10 PVS 1500	2373.89	9868.61	0.00	0.00	2237.97	10004.53
System Converter	80.37	66.09	0.00	0.00	24.02	122.44
Trina Tallmax M plus	50.38	0.00	14.12	0.00	0.00	64.50
System	5742.58	12928.75	1829.07	218106.69	4606.92	234000.17



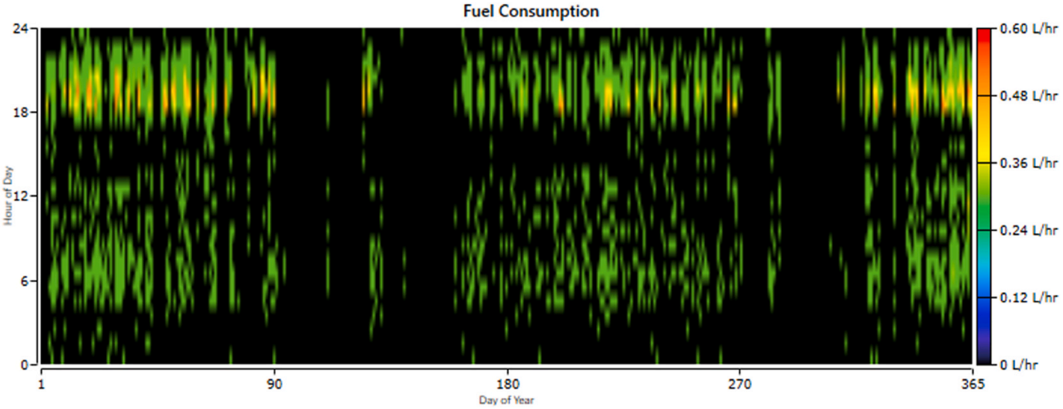
Appendix 20. Community Investment Sectors



Appendix 21. Electricity Production

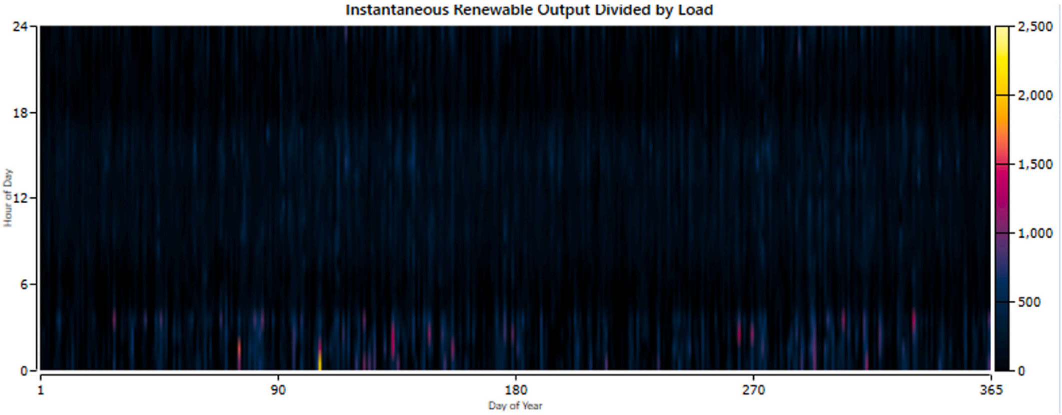


Appendix 22. Diesel Whisker Boxplot

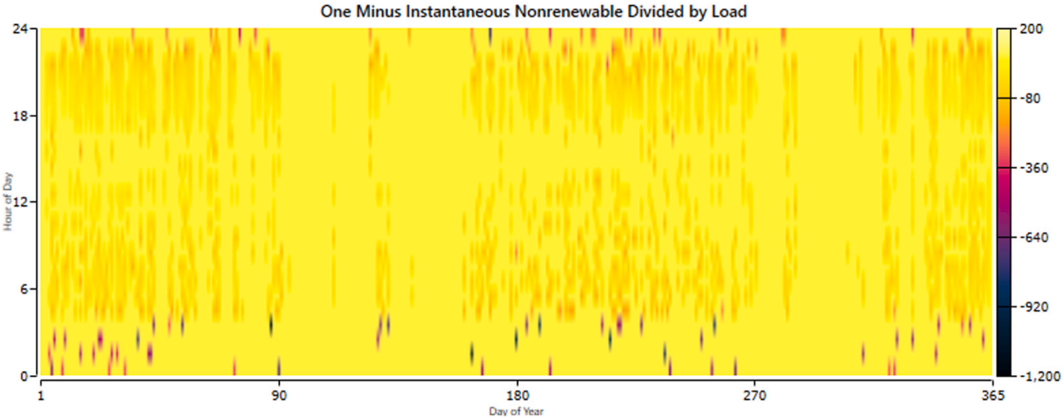


Appendix 23. Fuel Consumption Chart

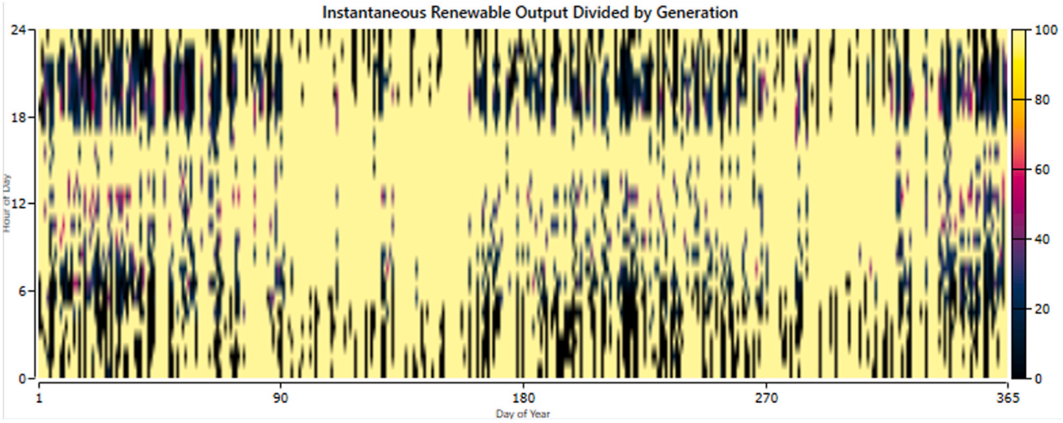
Appendix 24. Generator Power Output Chart



Appendix 25. Renewable Energy divided Electric Load



Appendix 26. Instantaneous Conventional divided load



Appendix 27. Renewable Output divided Generator

Solar PV (kW)	Wind Power (kW)	Generator Autosize (kW)	Storage Electricity (V)	System Converter (kW)	NPC (US$)	Initial Capital (US$)
		2.7		1.5	1085834.69	59.27
0.345	1	2.7	12	2.07	218970.65	5771.88

Appendix 28. Comparison Energy Factor

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