PLANNING AND ANALYSIS OF MICROGRIDS FOR CEMENT INDUSTRY

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JULY 2022

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Acknowledgements

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I would like to express my sincere gratitude to my supervisor Prof. Dr. Asad Waqar for their constant help, invaluable suggestions and encouragement that helped me in all the times to pursue this MS dissertation work.

ABSTRACT

Cement manufacturing is one of the most energy-intensive industries in the world. Most of the cost of producing cement is accounted by fuel consumption and power expenditures. Thermal power plants are the major source of electricity in Pakistan. But they are not efficient and environmentally friendly. This study simulates four different models for five cement plants of Pakistan on Homer Pro software and compares the optimal solutions based on the net present cost (NPC), levelized cost of electricity (LCOE) and greenhouse gas (GHG) emissions. Model-1 consists of solar panels, electrolyzer, hydrogen tank, hydrogen generator and converter. Model-2 has only a diesel generator and acts as a base case in this study. Model-3 has solar panels and a battery-converter system. In Model-4, diesel generators, solar panels and converters are considered. Based on NPC, the most optimal model is Model-4, having a 0.249 $/KWh LCOE in islanded systems. The NPC and operating costs are US$540 million and US$ 32.5 million per year, respectively, with a 29.80% reduction in CO2 emissions when compared to the base case. Based on GHG emissions, Model-1 and Model-3 are the best models with 0% GHG emissions. Sensitivity analyses is also performed using the parameters of load, inflation rate, and discounted rate. The results prove that the proposed hybrid micropower systems (HMS) can sustainably provide electricity for 24 hours a day to the sites under consideration with minimum objectives.

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ABBREVIATIONS

GHG	Greenhouse Gases
LCOE	Levelized Cost of Energy
CO_2	Carbon Dioxide
CRF	Capital Recovery Factor
HMS	Hybrid Micropower System
HOMER	Hybrid Optimization of Multiple Energy Resources
LF	Load Following
CC	Cycle Charging
NASA	National Aeronautics and Space Administration
NOx	Nitrogen Oxide
NPC	Net Present Cost
O & M	Operation and Maintenance
PV	Photovoltaic
RES	Renewable Energy Source
SO_2	Sulphur Dioxide
$C_{ann, the total}$	Total Yearly Cost
P_{in}	Input Power of Converter
P_L	Load Demand
P_{out}	Output Power of Converter
R_S	Amount of Solar Radiation Striking PV Array
T_C	PV Cell Temperature
T_p	Project Lifetime

CHAPTER 1

INTRODUCTION

1.1 Background

The installed capacity of cement in Pakistan exceeds 44 million tons per year and 110 to 120 kWh will make one ton of cement. Modest growth of 14% over the next five years for a further increase in production capacity. The cost of fuel and electricity accounts for 74% of all cement production costs. The cement industry in Pakistan consumes 720 MW of electricity, with electricity from the national grid getting used in coal-fired energy plants, which may be expensive and unpredictable. This project becomes even more dramatic in comparison to developing foreign areas like Pakistan, which faces a difficult task in meeting developing power demands for long-term development. For billions of people to escape poverty and experience an improvement in their level of living, sustainable development requires access to affordable, dependable, and efficient energy. The creation of new, renewable energy sources with lower CO2 emissions could not happen soon enough or at a price that enables people to achieve the level of life they want and deserve. As a result, a parallel route to sustainability that makes use of both clean carbon-based technologies and renewable ones must be created. Incorporating renewable energy sources like photovoltaics, wind, diesel production, or a mix of these sources, hybrid microgrids are pushed to address a variety of electrical and energy-related concerns. The use of microgrids in the production of electric power offers several advantages, including the use of renewable energy, improved grid stability, and decreased congestion. Despite these benefits, microgrid deployment is not common due to financial issues. It is vital to investigate the appropriate configuration of microgrids based on the amount, quality, and accessibility of sustainable energy sources utilized to establish the microgrid and the best design of microgrid components to meet these financial issues. Levelized energy cost and net present value reflect these factors.

1.2 Problem Statement

Element	Description
The problem of ...	Absolute Electricity utilization of cement industry in Pakistan is around 720 MW for which power from public lattice (as coal terminated power plants) and High-Capacity Genet is used. These oil and coal based nuclear power age advancements would be a significant wellspring of discharge and would contribute the most elevated measure of air toxin i.e., (CO, CO2, N2O,).
Affects ...	These emissions cause not only global warming, but also ozone depletion, soil, and water acidification, and pose a health risk.
And results in ...	The main health problems are dyspnea, sweating, fatigue, increased heart rate, and increased blood pressure.
Benefits of a solution ...	In this situation, it is necessary to use renewable energy in the future. Not only does it reduce costs, it also significantly reduces the public health risks of air pollution.

1.3 Novelty

The load must be carefully considered while using renewable energy sources in the cement sector. Most studies make assumptions about load levels without considering in-depth research on plant improvement, interest rate, and discounted rate characteristics. Furthermore, no one investigated the emissions produced by Pakistan's cement industries' use of electricity. This study aims to design a HES, cost-effective, and low-emission process for Pakistani cement industries while keeping this gap in mind. The project's primary objective was to find the optimal solution of the suggested system in terms of practical implementation under local conditions.

- Considering new rules and incentives for the technology, the objective of this study is to show the implementation of HMS in the cement industry.
- The viability of implementing a PV together with the Diesel also be studied, especially seeing how much Emission Reduced is by just adding PV.
- Four Different Models were Studied to consider the most feasible solution.
- The comparison of these implementations is done through economic analysis and GHG Emissions.
- As per the authors best knowledge it is a first study that deals with the implementation of hybrid micropower systems in the cement industry of Pakistan.

For this study five cement plants are under consideration.

Cement Plant-1: Askari Cement Plant, Wah.

Cement Plant-2: Bestway Cement Limited, Kalar Kahar.

Cement Plant-3: Bestway Cement Limited, Farooqia.

Cement Plant-4: Bestway Cement Limited, Hattar.

Cement Plant-5: DG Cement Limited, Chakwal.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

As the increasing population and industrialization of the world, energy deman d is rising swiftly. It is expected that between 2018 and 2050, global energy consumption will increase by almost 50%. Petroleum products have forever been the greatest provider to fulfill the high energy need, and this adversely influences the climate. A lot of poisons are delivered into the air when petroleum products are scorched, which makes hurts human wellbeing, other than making the environmental change due to the ozone harming substances impact [1]. The problem of a rise in Earth's surface temperature may be solved by reducing atmospheric carbon dioxide (CO2), which can be done by switching to cleaner energy sources [2]. Environmentally friendly power sources (RESs, for example, sun-oriented photovoltaic (PV), Figure 2.1 [3] shows the solar potential of Pakistan, sun-based warm, hydropower, geothermal, wind, and biomass, could offer serious expense choices, spotless and manageable energy to everybody, no matter what their geological area [4]. Half-breed energy frameworks (HESS) are created by combining RESs with conventional petroleum derivative-based generators, and they can overcome the issue of discontinuity and inconsistent RES supply. Compared to single energy sources, HESS can offer frameworks that are more dependable, controlled, and affordable [5]. The execution of

HES components may be most affected by the careful planning and preparation that went into them. The microgrid may be improved on every level to deliver the ideal operating conditions required to realize all models. While updating a framework plan, a single goal capability or multi-objective can be considered to discover the ideal configurations. If only one goal capability is being used, only one set of streamlining calculations should be performed. However, using multi-objective advancement computations is required when using at least two goal capabilities. A few instances of such targets incorporate boosting the framework's effectiveness and limiting its expense. To accomplish the best attainable arrangement of clear-cut enhancement issues, various strategies and procedures might be

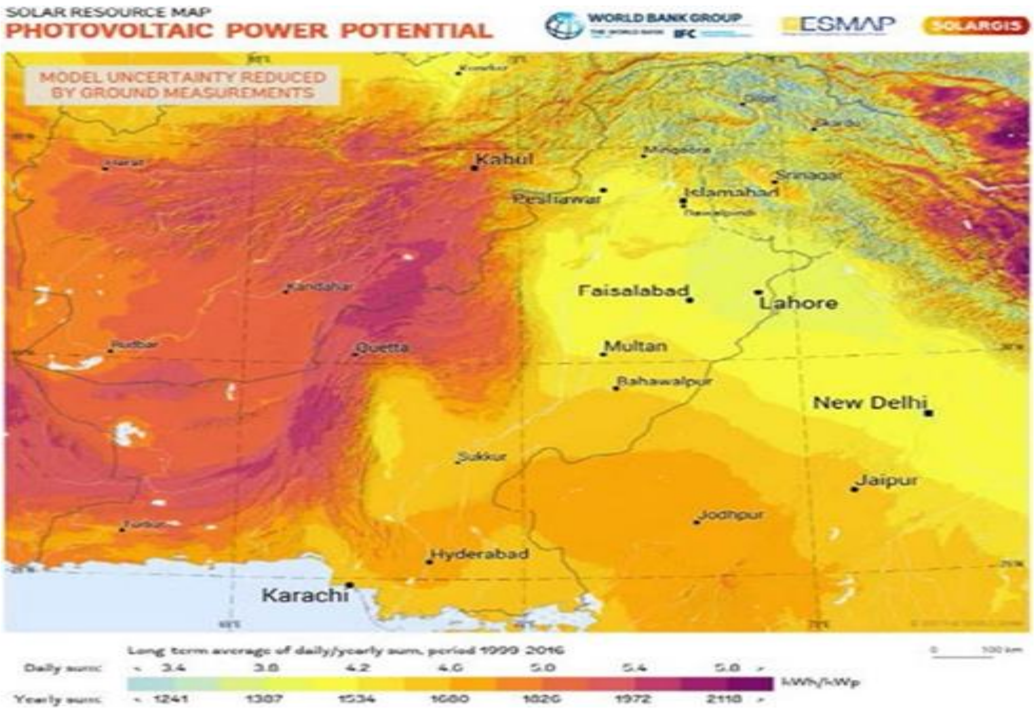

Figure 2. 1: Solar potential map of Pakistan

applied [6]. Molecule swarm enhancement, fluffy rationale, and hereditary calculations are a few instruments for the new age drawing near. Then again, severe cycles are executed for the conventional methodologies, including straight programming [7].

A few investigations have explicitly centered around the ideal plan of HESs utilizing variant streamlining methods. To take care of the estimating streamlining issue of an independent breeze/flowing/battery HES, an improved multi-objective measuring enhancement strategy given Halton grouping and the social rousing procedure was created in [8]. The creators observed that the upgraded calculation and proposed technique are proficient in improving the framework, and the framework's functional prerequisites are successful paired with the energy of the executive's methodology. The authors in [9] used inventive computing to address the HES estimation problem for PV, wind, diesel, and batteries. In Saudi Arabia, a constrained small area is zapped using the proposed HES. The findings confirmed the calculation's supremacy and legitimacy in analyzing the ideal HES estimate. Hemeida et al. [10] did research to determine the optimum approach for a hybrid sustainable framework in Libya using both crow calculations and molecular swarm optimization. The crow calculation was shown to be more useful and efficient than the molecular swarm advancement calculation an improvement model with many objectives created in [11] determines the crossover system between different sources configuration. Application results helped to validate the framework's viability. Using HOMER, which stands for HRES, [12] to control whether it is possible to power a private location in Palestine with a sustainable PV/biomass combination system, both technically and economically. The creators thought the suggested technology may reduce pollutants while simultaneously providing clean energy. Cao et al. [13] For a PV/wind/energy unit/battery HES, multi-objective streamlining was used using the elephant crowding improvement calculation. It was determined that the suggested strategy is an effective option to use for the optimum design of a half-and-half age framework. To provide energy to remote areas, it was suggested to investigate the best configuration of a HES made up of solar, wind, and batteries using a metaheuristic grasshopper improvement computation [14]. In [15], An energy channel calculation was used to determine the best measurement technique for a PV, wind turbine, and battery crossover age architecture. In addition to satisfying the necessary constraints, the designers discovered that using the energy channel calculation with the suggested technique is useful for locating the ideal financial arrangement for the HES.

Lattice coupled and independent HESs that combine traditional energy sources with cogeneration, solar, hydropower, wind, biomass, batteries, energy units, and other information sources are planned and researched using HOMER, the most widely used tool for leisure programming. The client can assess the HES's technological, financial, and ecological viability for a specified undertaking lifetime thanks to HOMER's upgrade capabilities. The feasible framework in HOMER is the one that allows for the proper fulfillment of the electrical and thermal loads as well as other needs. The most un-net present expense (NPC)-rich design is regarded as the best framework. Other than the NPC, other outcomes from the ideal framework include the cost of energy (COE), the dimensions of each component and the power output, the inexhaustible portion, fuel use, poison outflows, and other ordinary outcomes. Additionally, a responsiveness analysis may be carried out to investigate the various effects of fundamental limits on the display of a crossbreed age framework. [16]. In [17] Contributions to reproduction fall into six major categories: meteorological data, load profiles, part subtleties, control procedures, crucial data, and responsiveness esteem. The plausibility is not unchangeable throughout the recreation step. The outcomes include the ideal framework, technological, financial, and natural performance, as well as awareness examination findings.

The accessibility of RESs, suitable control methods, and a framework's equipment components must all be carefully examined to arrive at the perfect framework part estimations [18]. Energy the board control frameworks are required to ensure safe operations and achieve the set goals. They are also required to enable the activity, joining, and connectivity of multiple elements in a single age framework. To work on the exhibition and propose a techno-financial practical decision, suitable energy the board technique permits the framework to address the heap, decreasing both energy costs and ozone depleting substance discharges, and increasing the parts' lifetime [19, 20]. When the heap cannot be met by the RESs alone, generator, battery dispatch management are considered [21]. LF and CC are the two dispatch methods in homer. Without taking into consideration the future burden profile or source conditions, these approaches choose the most plausible configuration that can meet the power interest at each time step. When using the LF and CC dispatch techniques, the generator performs substantially differently. With the LF approach, generator meet the load requirements without charging the battery. RESs are used during this process to charge the battery. Generator operates at maximum capacity and forbids having access to more power during the CC operation [22].

The enhancement of the HESs plan in HOMER while taking both LF and CC strategies has been the focus of most of the test research. In [23], In India, HOMER is perfectly used to plan an off-matrix HRES for a provincial charge. According to the inventors, the CC method outperforms the LF method from a financial standpoint. The investigation in [24] it was considered to have HES using the LF approach multicriteria arranging to meet the demand for energy in a rural Tanzanian location. The results demonstrated that the proposed HES is an innovative method for billing the chosen location. Elkadeem Ma et al. [25] examined if a HES and an opposite assimilation desalination plant might be combined to supply water and energy for Egypt's international airport. The CC approach was used to guarantee the energy stream control between the components. The outcomes showed that the suggested HES is useful in terms of knowledge, resources, and funds. In Malawi, an optimum framework with a mix of ages for a contextual analysis was examined [26]. The LF and CC dispatch systems were used to conduct the analysis. According to the long-term research, the most typical configuration uses a for the LF technique. In Nigeria [27], the system was examined from the perspective of technical and financial shock. The LF approach was used to control the energy stream between the components. It was deduced from the comparative analysis and exploratory findings that the suggested framework is a strong option for own lattice provincial jolt. Nesamalar et al. [28] used the LF and CC approaches in both off-framework and on-framework to provide a specialized and An Indian educational facility's PV/diesel/battery HES's financial analysis. The on-lattice HES utilizing LF dispatch was discovered to be the best strategy for the suggested place. To manage the activity of a hybrid sustainable aging framework in Turkey, the developers investigated using the LF and CC approaches. The framework using the CC technique was thought to have lower COE and NPC than the framework using the LF methodology. The shock of a provincial area in Malawi was evaluated for an ideal HES design in [29]. The CC approach was used to look at the energy transfer between the various framework components and the heap. Variations in wind speed and fuel price during the project's lifecycle, it has been shown, have a detrimental influence on the NPC. In [30], the Designers of the framework assessed the technical, financial, and energy advantages of utilizing In order to supply electricity to a specific site in Minya City, Egypt, a PV, diesel engine, and battery were used. The findings indicate that the LF system performs better in terms of financial execution than the CC method. A correlation of HESs in eight environmental zones of Iran was done utilizing the CC technique from a techno-monetary perspective in [31]. The ideal HES was thought to be a combination of a lattice, PV, and wind turbine. An independent breeze/flowing/diesel HES was investigated in New Zealand for the jolt of seaside networks for plan streamlining using the LF technique. [32]. The findings suggested that the ideal HES plan is set up to provide pleasant technical, financial, and natural execution.

CHAPTER 3

METHADOLOGY

3.1 Overview

This power-generating system's design incorporated HMS. Figure 3.1 depicts the approach system.

- To optimize the microgrid system, HOMER receives data such as load demand, component specifications, and meteorological data, such as solar irradiance data.
- Available resources are selected for the analysis. Techno-economic analyses are performed to get the most optimal solution according to NPC and GHG emission reduction.
- Sensitivity analyses are performed using 30%, 60%, 90%, 120%, and 150% load, the Inflation rates of 10, 14, and 18%, and the discounted rate of 25, 35, and 50%.
- HOMER examines every combination in the enumerative optimization process, gives a list of the best solutions and arranges them in accordance with the chosen

optimization variable after they are unable to satisfy restrictions (NPC).

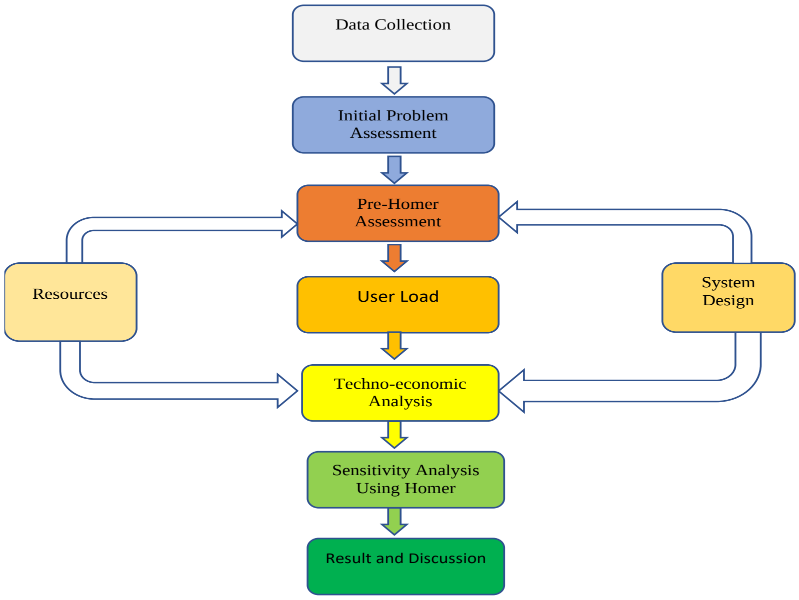

Figure 3. 1: Methodology framework of the hybrid microgrid design

3.2 Optimization Technique

NREL created an optimization program called as HOMER. Additionally, HOMER enables customers to compare the technical and economic benefits of alternative generating and storage unit configurations. The user input load profile and solar irradiation, the producing and storage units to be taken into consideration, and their prices. After simulating all possible configurations optimal solution is ranked by lowest (NPC).

HOMER uses a derivative free optimizer. The optimization algorithm makes use of an altered grid search method. The user enters several parameters (as inputs) and HOMER find the optimum solution. HOMER perform simulation on the provided data [33]. Based on objective HOMER filtered the optimal solution.

3.3 Goals and Limitation

The optimum configuration is influenced by several variables. A few of the many objectives include lowering yearly greenhouse gas (GHG) emissions, the LCOE produced, and the microgrid's (NPC).

3.4 Net Present Cost

The various ongoing cost combination is equivalent to NPC that framework experienced throughout the course of its specified useful life, less the recovery value during that time. The costs shown in equation (1) according to reference [34] for capital expense, substitution cost, activity, and upkeep cost are the costs that are recalled for the net present expense. The introduced framework's components each have their NPC calculated using Homer expert programming.

The formula below is used to determine the total NPC:

$$C_{NPC} = \frac{C_{ann.tot}}{CRF\left(i\,.\,R_{proj}\right)} \tag{1}$$

Here, $C_{ann,tot}$ = Annualized cost. i = Interest rate (Annual). R_{proj} = Project lifetime.

CRF (.) = Capital recovery factor.

3.5 Levelized Cost of Energy

A typical cost per KWh of power is delivered by the predetermined shaped framework. To determine the optimal COE for a standalone system, HOMER uses the equation (2) from [34]:

$$LCOE = \frac{C_{ann.tot}}{E_{prim} + E_{def} + E_{grid.sales}} \tag{2}$$

E_{def} = total deferrable load, E_{prim} = entire primary load, $C_{ann.\ tot}$ is the yearly total cost, and Egrid,= energy supplied to the grid (per year).

3.6 Total Annualized Cost

The sum occur yearly while the project is being evaluated and will supply the NPCs required to satisfy the part-income request. The overall annual cost is determined using NPC and raised with the capital recovery factor utilizing Homer Ace programming.

3.7 Hybrid Micro Grid Model Designing

Employing the Homer Pro Software, four models were created for the techno-economic analysis using a range of components for renewable and non-renewable sources. The suggested system includes a hydrogen tank, electrolyzer, hydrogen generator, fuel cells, converters, batteries for backup and storage, and generators for peak load requirement For each model, the most sensible and cost-effective options are provided, and each has its gains and boundaries to fulfill necessary load requirements following is a list of the four types of models that are created for this hybrid renewable system.

- Model-1: As shown in Figure 3.2(a), it will have a PV module, hydrogen tank, converter, electrolyzer, and energy component.
- Model-2: As shown in Figure 3.2(b), it will only have a diesel generator.
- Model-3: As shown in Figure 3.2(c), it will have a PV module, converter, and battery framework.
- Model-4: As shown in Figure 3.2(d), it will have a diesel generator, PV module, and Converter.

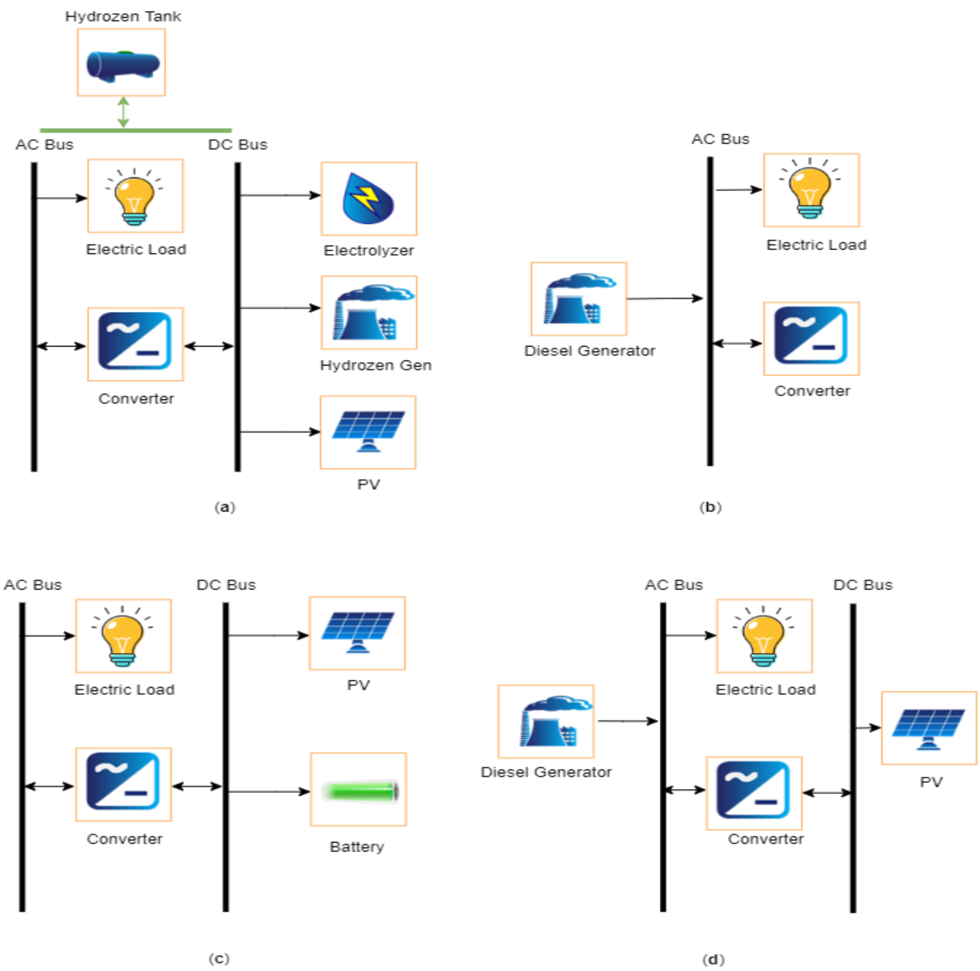

Figure 3. 2: Schematic diagram of Models (a) Model-1 (b) Model-2 (c) Model-3 (d) Model-4

3.8 Site Area

For the targeted cement Industries of Askari Cement, Bestway Cement Limited, and DG Cement Limited, a renewable hybrid energy system would be constructed. Wah, Kalar Kahar, Farooqia, Hattar, and Chakwal are the locations of these industries.

3.9 Load Profile

The load profile for five cement factories: For Askari Cement, wah, is 432000KWh/day. The average load for Bestway Cement Kalar kahar, Farooqia, and Hattar, is 816000KWh/day, 888000KWh/day, and 432000KWh/day respectively. The daily load for DG cement in Chakwal is 744000KWh. In Figures 3.4-3.8, daily and seasonal load profiles are depicted. In Figure 3.3 Energy consumed per day is shown.

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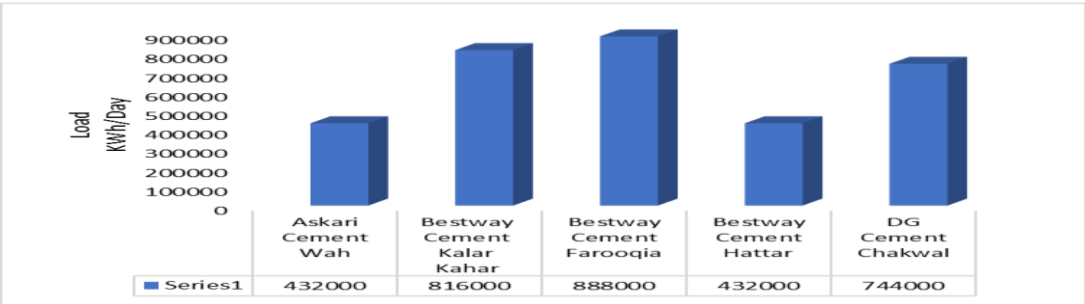


Figure 3. 3: Daily Energy of the Plants

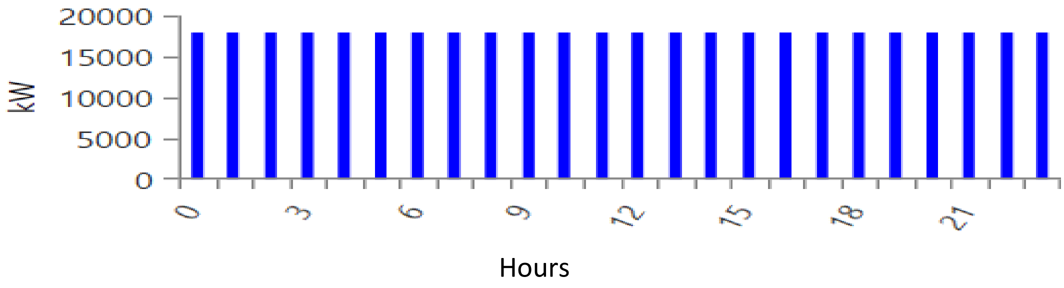


Figure 3. 4: Plant-1's Daily Load Profile

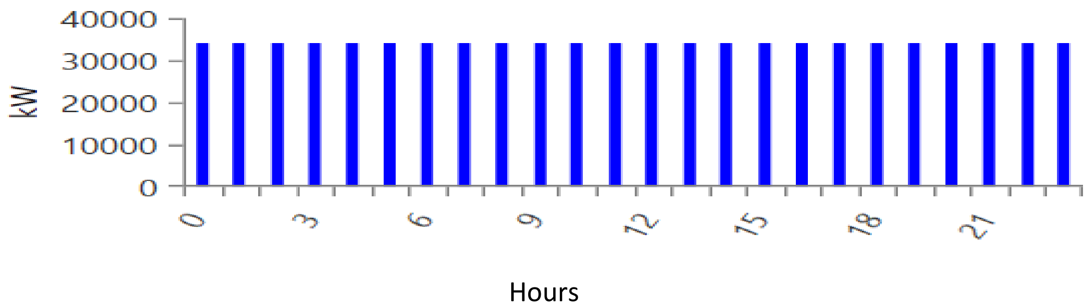


Figure 3. 5: Plant-2's Daily Load Profile

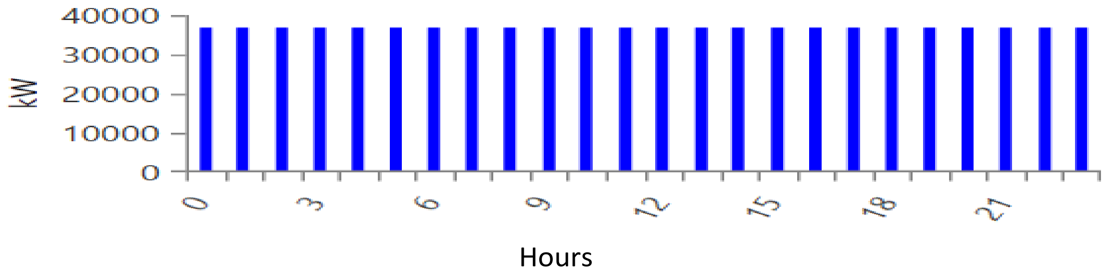


Figure 3. 6: Plant-3's Daily Load Profile

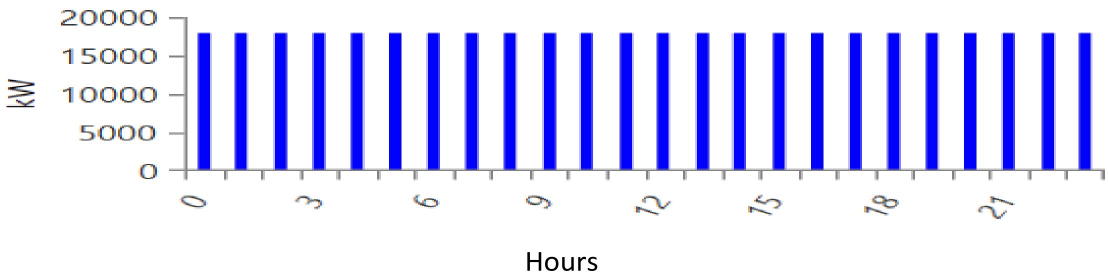


Figure 3. 7: Plant-4's Daily Load Profile

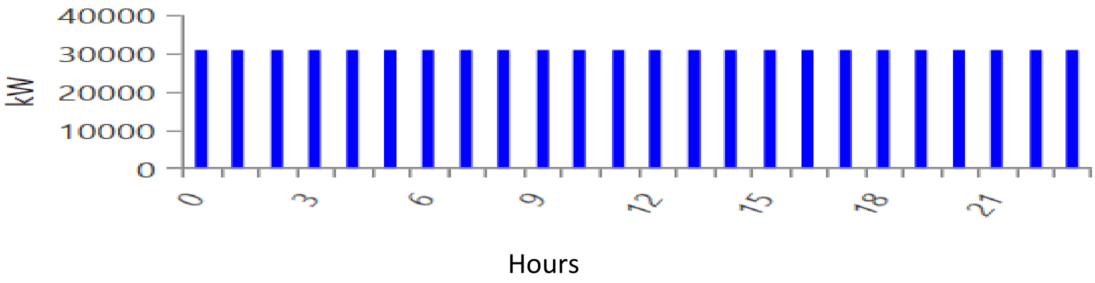


Figure 3. 8: Plant-2's Daily Load Profile

3.10 Energy Resource Assessment

Information about the potential for energy resources depends largely on the location of the area. In Pakistan, information on the potential for wind and solar energy is widely available. When assessing the resource potential of the probable places, their geographic position has been considered.

3.10.1 Solar Energy Asset Potential

The chosen destinations for the Half and half model of inexhaustible assets have an incredible potential for sun-oriented radiation. The month-to-month clearness record and sunlight-based radiation of Plant-1 to Establish 5 are displayed in Table 3.1. The yearly typical temperature for Plant-1 is 22.85 degrees Celsius. For Plant-2, the yearly normal temperature is 17.80 degrees Celsius. For Plant-3, the yearly normal temperature is 22.75 degrees Celsius. For Plant-4, the yearly normal temperature is 22.75 degrees Celsius. For Plant-5, the yearly normal temperature is 24.21 degrees Celsius as displayed in Figure 10. The yearly unambiguous photovoltaic power yield for Plant-1 is 1620 kWh/kWp. For plant-2 explicit photovoltaic power yield is 1631kWh/kWp. While for Plant-3, and Plant-4 the PV OUT is 1621 kWh/kWp. For

Plant-5 it will be 1651kWh/kWp. Figure 3.9 shows the annual daily radiation in kWh/m2/day. The yearly average radiations for Plants-1 and 2 are around 4.91, for

Table 3. 1: Average monthly values for solar (kWh/m2/day), wind (m/s), and clearness index

Month	Plant-1	Plant-2	Plant-3	Plant-4	Plant-5
	Solar radiation	Solar radiation	Solar radiation	Solar radiation	Solar radiation
Jan	3.088	2.995	3.087	3.087	3.2
Feb	3.841	3.822	3.87	3.87	4.003
Mar	4.737	4.795	4.77	4.77	4.8
Apr	5.847	5.849	5.826	5.826	5.952
May	6.77	6.771	6.733	6.733	6.783
Jun	7.04	7.004	7.063	7.063	6.982
Jul	6.233	6.051	6.075	6.075	6.316
Aug	5.458	5.468	5.357	5.357	5.725
Sep	5.35	5.399	5.315	5.315	5.594
Oct	4.574	4.696	4.6	4.6	4.68
Nov	3.452	3.54	3.474	3.474	3.567
Dec	2.562	2.576	2.566	2.566	2.732
Jan	4.912	4.913	4.894	4.894	5.027
Annual Average	3.088	2.995	3.087	3.087	3.2

Plants-3 and 4, they are 4.89, and for Plant-5, they are 5.027 kWh/m2/day. Pakistan experiences 5.0 kWh/m2/day on average of daily sun radiation, which is roughly what is anticipated for the development of solar-powered chargers. The number of web-based data sets that are available can be used to estimate sun-based radiation information. These data were obtained from the NASA website, WorldweatherOnline, and a book of maps that are oriented toward the sun [35].

Table 3. 2: Components cost [3]

Components	Initial cost US$/kW	Replacement cost US$/kW	Operating cost	Lifetime in years
PV panel	350	350	10	25
Diesel gen	400	400	0.010	15,000 h
Battery	4400	1320	8	20
Converter	300	300	0.00	15
Fuel cell	400	400	0.010	15,000 h
Electrolyzer	100	100	8	15
Hydrogen Tank	1/kg	1/kg	8/year	25

3.11 Microgrid Components

The suggested systems' hybrid model is made up of many component kinds. Table 3.2 provides the component prices. The discussion of these elements follows.

3.11.1 PV Arrays

In the produced variations, generic flat-plate photovoltaic is utilized. Generic PV panels have a 25-year lifespan and a 14 % efficiency. Each PV plate has a one kW rating. It is anticipated that a photovoltaic system will cost US$350/kW to purchase, US$350/kW to replace, and US$10/kW to operate. The solar array's derating factor is around 80%. The tracking device was positioned on a vertical axis with continuous adjustment since the ground has a 20% reflectivity. Equation (3) [36] calculates the module's output power under normal working conditions.

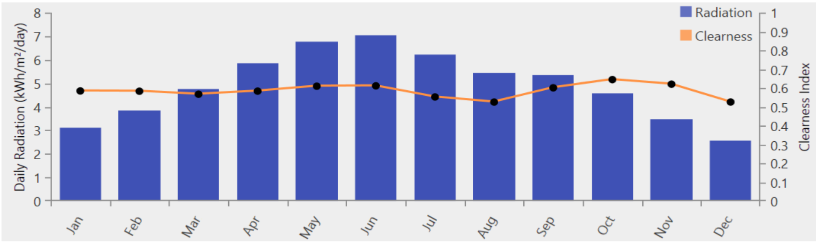
$$P_{pv} = f_{pv} \times Y_{pv} \times \frac{I_T}{I_S} \tag{3}$$

P_{pv} stands for the nominal power output of PV panels in kilowatts (kW); I_T stands for the total incident radiation (kWh/m2); I_S = 1000 W/m^2; and f_{pv} stands for the reduction factor, which is dependent on things like energy loss brought on by long wiring distances, and splices.

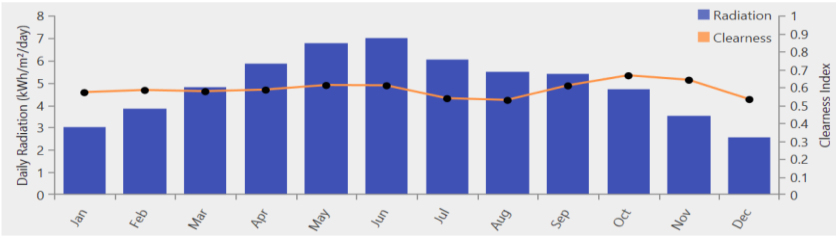
According to equation (4) according to reference [36], The investigation must take into account the photovoltaic cells' temperature since it is important.

$$TC = T_{amb} + GS\left(\frac{NOCT - 25}{1000}\right) \tag{4}$$

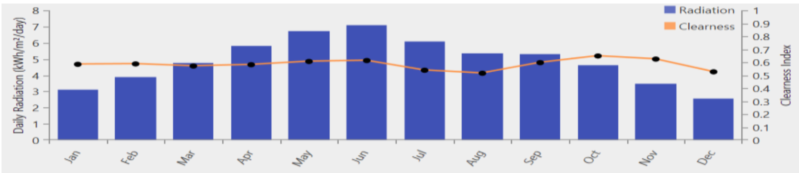
The ambient temperature (T_{amb}), the localized global solar radiation (GS), and the normalized operating temperature (NOCT) are all calculated using a baseline ambient temperature of 20℃ and a global radiation density of 800 W/m^2.



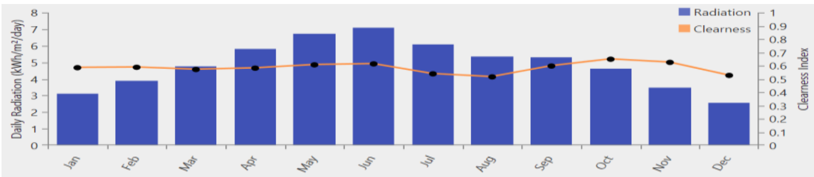
a) Plant-1



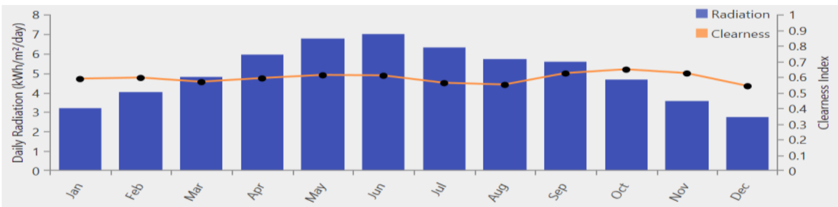
b) Plant-2



c) Plant-3



d) Plant-4



e) Plant-5

Figure 3. 9: Annual daily radiation and clearness index

3.11.2 Battery Storage System

Utilizing a Generic energy cell with a 20 kW–72 kWh capacity, the proposed gadget. We'll think about the hybrid model 1's power storage system. A 20-year estimated lifespan applies to this zinc-bromine battery.

The battery requires an initial investment of $4400, a replacement cost of $1320, and annual operating costs of $8. From equation (5) as in [37], the roundtrip efficiency of the battery is around 80%, a nominal voltage of 12 volts, a maximum charge current of 16.7 amps, and a maximum discharge current of 24.3 amps.

$$SOC(t) = SOC(t-1)(1-\sigma) + (P_{GA}(t) - \frac{P_L(t)}{\eta_{inv}})\ \eta_{battery} \qquad (5)$$

PL(t) = Load Demand. The battery's level of charge is given as SOC (t).

The ceil places the expression in the collection of expressions that are close to or equal to the total. In a hybrid system, the battery bank serves as storage, but it also maintains the proper balance between supply and demand for electricity. Energy output, consumption, and charge status are all assessed in relation to time.

3.11.3 Converter

A Generic system converter, which is part of the Homer pro software, is used with this model. It can operate in rectifier and inverter modes. The converter only functions in inverter mode when solar and wind resources are not available; this mostly happens at night and in cloudy weather. Only when there is sufficient renewable energy to fully charge the battery storage system does the converter switch to rectifier mode. The efficiency of the converter is listed at 95%. A one-kilowatt converter is thought to cost roughly $300. Replacement costs about $300 and has a 15-year lifetime.

The power converter's maximal ability to convert DC to AC depends on the efficiency and choice of the inverter ($P_{l,s}$ (t)). It is expressed as equation (8) in [38]:

$$P_{l,s}(t) = P_{input}(t) * \eta_{conv} \qquad (6)$$

where P_{input}(t) identifies the input power of the converter and its efficiency.

3.11.4 Diesel Generator

In Model 2, the design and simulation processes employ a generic small-size generator. The Homer Pro program adjusts the generator to meet its needs. The estimated lifespan, with a minimum load ratio of 25%, is 15,000 hours. The hourly costs for capital, replacement, and operation are, respectively, $400, $400, and $0.010. The fuel for the diesel generator costs US$0.66, US$0.75, and US$0.80 and lasts for 15,000 hours.

The connection depicted in equation (7) from [39] establishes a connection between a diesel generator's output and rated power.

$$PGD = \eta diesel \times NDG \times PGD, N \qquad (7)$$

where NDG = total number of identical diesel generators, PDG = combined output power of the generators, and η is the efficiency of the generator.

Using equation (8) above, the predicted CO2 emissions from the hybrid system were calculated [34]:

$$tCO_2 = 3.667 \times m_f \times Hv_f \times CEF_f \times x_c \qquad (8)$$

The amount of fuel is shown by m-f, and the total CO2 emissions are indicated by t_C, and O2. The abbreviations H_{vf}, CEF_f, and Xc stand for Tons of Carbon Emitted per TJ, the percentage of oxidized carbon, and Heating Value of Fuel in MJ/L, respectively. The fact that 1 gramme of carbon is present in 3.667 grammes of CO2 is one final thing to consider.

3.11.5 Fuel Cell

Since fuel cells mix hydrogen and oxygen to make energy, they are essentially the opposite of electrolysis. Even though hydrogen fuel cells are very effective and only produce water as a byproduct, they are expensive to produce. On the other hand, because of its expensive cost and risky nature, hydrogen will not be employed to create power on a wide scale. The oxidation of hydrogen gas in the anode region as shown in equation (9) from [40].

Equation of anode

$$2H_2 = 4H^+ + 4e^- \tag{9}$$

In addition to interacting with the electrons from the electrodes at the cathode, oxygen reacts with the ions.

Water is removed as waste product. At the cathode, electrons combines with oxygen and H+ ions. In addition to interacting with the electrons from the electrodes at the cathode, oxygen also does so with the ions from the electrolyte and water.

Water is the waste product and removed. Water and H+ ions from the electrolyte are joined by oxygen, together with electrons from the electrodes, at the cathode equation (10) shows the reaction [40].

$$O_2 + 4e^- + 4H^+ = 2H_2O \tag{10}$$

Fuel cell is the small size generator and connected to the system through a direct current bus. When neither solar nor wind energy is available during peak power, the fuel cell technology employed in this model serves as a backup. A fuel cell has a $400 kW initial cost, a $400 kW replacement cost, and an operating cost of $0.10 per hour. A fuel cell has a total life of 15,000 hours.

3.11.6 Electrolyzer

Based on the generic electrolyzer, this model. Water is converted into hydrogen and oxygen molecules in an electrolyzer. Electrolysis is the name for this procedure. The electrolyzer generates electricity using hydrogen. A 1 kW electrolyzer is expected to have a replacement and capital expenditures of $100 and operating expenses of $8/kW. The Model 3's electrolyzer has an efficiency of 85% and a 15-year lifetime.

When water is electrolyzed, oxygen gas is released at the anode area along with electrons and hydrogen ions.

Anode Reaction showed In equation (11) according to [41].

$$2H_2O \rightarrow O_2 + 4e^- + 4H^+ \quad (11)$$

When hydrogen ions and electrons react, hydrogen gas is released in the cathode area.

Cathode Reaction showed in equation (12) from [41]

$$4H^+ + 4e^- \rightarrow 2H_2 \quad (12)$$

3.11.7 Hydrogen Tank

Hydrogen is stored in a hydrogen tank. Fuel cells are powered by the hydrogen that has been conserved in this process. A hydrogen tank has a capital cost of $1 per kilogram. The yearly operating costs are US$8, and the replacement cost is equivalent to US$1/kg. The hydrogen tank can be as little as 1 kilogram or as large as 300 kg. The hydrogen tank was meticulously designed to last 25 years.

CHAPTER 4

Results

4.1 Overview

To find the most effective system, the simulation was run in the Homer Pro software using the NPC and LCOE values indicated earlier in this section. By altering the component's values, the output may be modified. A sensitivity variable test may be used to determine which hybrid system is the most practical, and by doing so, we can improve the system's NPC and LCOE.

4.2 Askari Cement Limited, Wah Plant

4.2.1 Model-1 Results

With the combined power of 39,000 kW of generators and 283,501 kW of PV, Askari Cement Factory Road, Wah, Rawalpindi, Punjab, Pakistan's electrical demands are covered. Currently, you spend $146M annually on energy operational expenses.

4.2.1.1 Electrical Production:

With a peak power of 286601 kW, this microgrid uses 1532729 kWh each day. The following generating sources power the electrical load in the system as suggested.

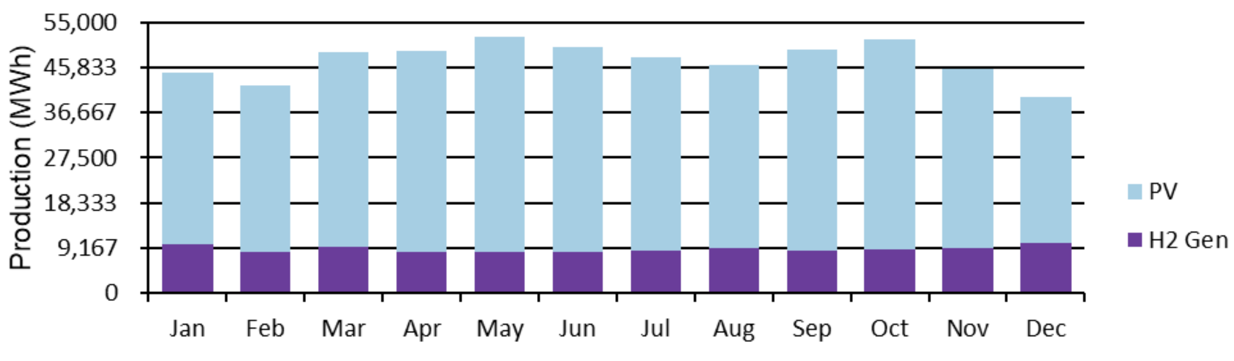


Figure 4. 1: Electrical Production from Model-1 for Plant-1

Generic flat plate PV			
Capacity Rating	283,501 kW	Total Production	460,251,968 kW
Investing Cost	$99.2M	Maintenance Cost	2,835,006 $/yr
Specific Yield	1,623 kWh/kW	LCOE	0.0219 $/kWh
PV Penetration	292 %		
Auto size Genset (Stored Hydrogen)			
Capacity	39,000 kW	Generator Fuel	Stored Hydrogen
Operational Life	2.24 yr	Generator Fuel Price	1.00 $/kg
Capital Cost	$15.6M	Maintenance Cost	2,612,220 $/yr
Fuel Consumption	8,610,945 kg	Electrical Production	107,375,736 kWh/yr
Hours of Operation	6,698 hrs/yr	Marginal Generation Cost	0 $/kWh
Fixed Generation Cost	1,430 $/hr		
System Converter			
Capacity	30,292 kW	Hours of Operation	8,760 hrs/yr
Normal Output	17,999 kW	Energy Out	157,669,712 kWh/yr
Lowest Output	867 kW	Energy In	165,968,112 kWh/yr
Optimal Output	30,292 kW	Losses	8,298,406 kWh/yr
Potential Factor	59.4 %		
Electrolyzer			
Initial Capital	$500M	Operating Expenses	40,000,000 $/yr
Rated Capacity	5,000,000 kW	Capacity Factor	0.917 %
Total Input Energy	401,659,584 kWh/yr	Total Production	8,655,481 kg/yr
Hours of Operation	4,162 hr/yr	Specific Consumption	46.4 kWh/kg
Minimum Output	0 kg/hr	Maximum Output	5,781 kg/hr
Hydrogen Tank			
Hydrogen Storage Capacity	10,000,000 kg	Energy Storage Capacity	333,333,344 kWh
Content at Beginning of Year	1,000,000 kg	Content at End of Year	1,044,536 kg
Tank Autonomy	18,519 hr		

4.2.2 Model-2 Results:

A 37,000-kW generator is used to supply electricity to Askari Cement Factory Road in Wah, Rawalpindi, Punjab, Pakistan. The annual running energy expenses are $40.8M.

4.2.2.1 Electrical Production

A high of 32998 kW is reached by this microgrid, which uses 431910 kWh each day. The electrical load in the proposed system is supplied by the following generating sources.

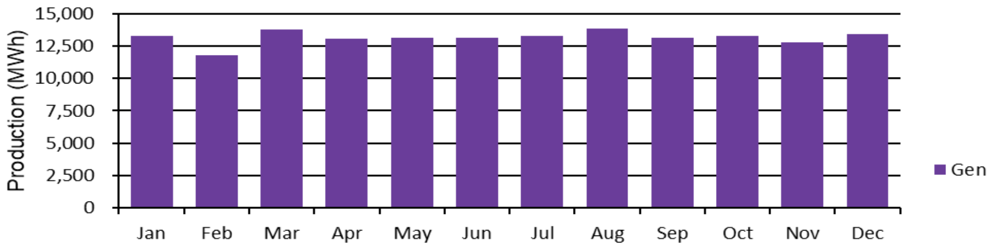


Figure 4. 2: Electrical Production from Model-2 for Plant-1

Auto size Genset (Diesel)			
Capacity	37,000 kW	Generator Fuel	Diesel
Operation life	1.71 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$14.8M	Maintenance Cost	3,241,200 $/yr
Fuel Consumption	42,002,772 L	Electrical Production	157,848,192 kWh/yr
Hours of Operation	8,760 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	1,737 $/hr		

4.2.3 Model-3 Results:

With 950,555 kW of PV and 611,875 kWh of battery capacity, Askari Cement Factory Road, Wah, Rawalpindi, Punjab, Pakistan's electrical demands are satisfied. Currently, your annual running expenditures for energy are $139M.

4.2.3.1 Electrical Production

With a maximum capacity of 32998 kW, this microgrid uses 431638 kWh each day. The electrical load in the suggested system is supported by the following generating sources

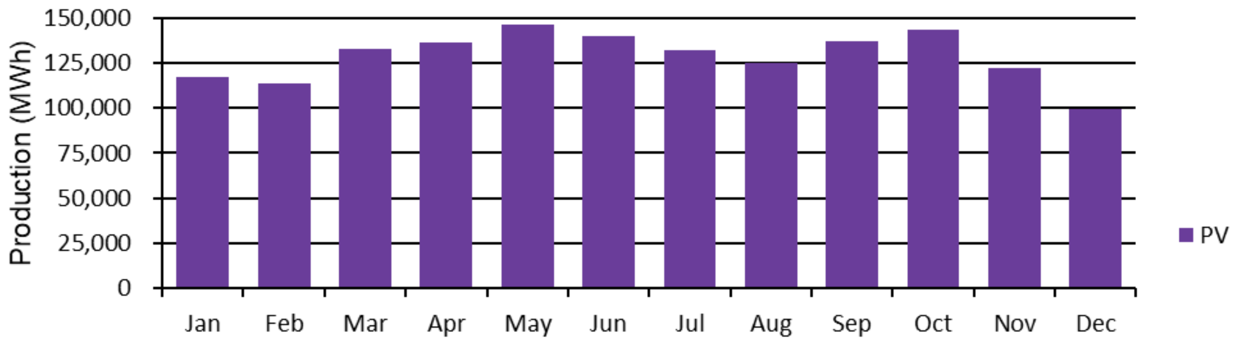


Figure 4. 3: Electrical Production from Model-3 for Plant-1

Generic flat plate PV			
Capacity Rating	950,555 kW	Total Production	1,543,188,736 kW
Investing Cost	$333M	Maintenance Cost	9,505,555 $/yr
Specific Yield	1,623 kWh/kW	LCOE	0.0219 $/kWh
PV Penetration	979 %		
Generic 1kWh Lead Acid			
Rated Capacity	611,875 kWh	Expected Life	5.17 yr
Annual Throughput	94,526,840 kWh/yr	Capital Costs	$2.69B
Maintenance Cost	4,891,088 $/yr	Losses	21,116,278 kWh/yr
Autonomy	20.4 hr	Expected Life	5.17 yr
System Converter			
Capacity	115,659 kW	Hours of Operation	8,760 hrs/yr
Normal Output	17,988 kW	Energy Out	157,579,008 kWh/yr
Lowest Output	0 kW	Energy In	165,872,640 kWh/yr
Optimal Output	32,998 kW	Losses	8,293,632 kWh/yr
Potential Factor	15.6 %	Hours of Operation	8,760 hrs/yr

4.2.4 Model-4 Results

We suggest a PV addition of 207,000 kW. Your operational costs would drop to $32.4M per year as a result. Your investment has an IRR of 9.60 percent and a payback period of 9.16 years.

4.2.4.1 Electrical Production

This microgrid has a peak power of 32998 kW and daily energy consumption of 431910 kWh. The electrical load in the suggested system is supported by the following generating sources

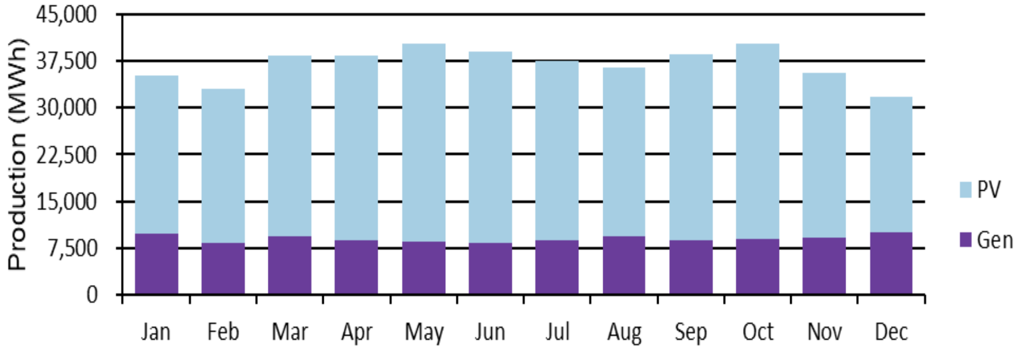


Figure 4. 4: Electrical Production from Model-4 for Plant-1

Generic flat plate PV			
Capacity Rating	207,000 kW	Total Production	336,056,992 kW
Investing Cost	$72.5M	Maintenance Cost	2,070,005 $/yr
Specific Yield	1,623 kWh/kW	LCOE	0.0219 $/kWh
PV Penetration	213 %		
Auto size Genset (Diesel)			
Capacity	37,000 kW	Generator Fuel	Diesel
Operational Life	2.05 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$14.8M	Maintenance Cost	2,701,740 $/yr
Fuel Consumption	29,485,466 L	Electrical Production	108,156,680 kWh/yr
Hours of Operation	7,302 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	1,737 $/hr		
System Converter			
Capacity	28,642 kW	Hours of Operation	4,359 hrs/yr
Normal Output	5,667 kW	Energy Out	49,643,004 kWh/yr
Lowest Output	0 kW	Energy In	52,255,796 kWh/yr
Optimal Output	26,035 kW	Losses	2,612,790 kWh/yr
Potential Factor	19.8 %		

4.2.5 Models Evaluation:

Model-1

	Base System	Proposed System
Net Present Cost	$2.63B	$2.63B
CAPEX	$634M	$634M
OPEX	$146M	$146M
LCOE (per kWh)	$1.22	$1.22
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	8,610,945	8,610,945

Model-2

	Base System	Proposed System
Net Present Cost	$575M	$575M
CAPEX	$14.8M	$14.8M
OPEX	$40.8M	$40.8M
LCOE (per kWh)	$0.266	$0.266
CO2 Emitted (kg/yr)	109,947,100	109,947,100
Fuel Consumption (L/yr)	42,002,770	42,002,770

Model 3

	Base System	Proposed System
Net Present Cost	$4.97B	$4.97B
CAPEX	$3.06B	$3.06B
OPEX	$139M	$139M
LCOE (per kWh)	$2.30	$2.30
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	0	0

Model 4

	Base System	Proposed System
Net Present Cost	$575M	$540M
CAPEX	$14.8M	$95.8M
OPEX	$40.8M	$32.4M
LCOE (per kWh)	$0.266	$0.249
CO2 Emitted (kg/yr)	109,947,100	77,181,600
Fuel Consumption (L/yr)	42,002,770	29,485,470

4.3 Bestway Cement Limited, kalar kahar Plant

4.3.1 Model-1 Result:

Bestway Cement Ltd.'s Kalar Kahar Plant's electrical requirements are satisfied with 531,251 kW of PV and 73,000 kW of generator capacity. Currently, your annual running expenditures for energy are $156M.

4.3.1.1 Electrical Production

This microgrid has a peak power of 533576 kW and daily energy needs of 2887085 kWh. The electrical load in the suggested system is supported by the following generating sources.

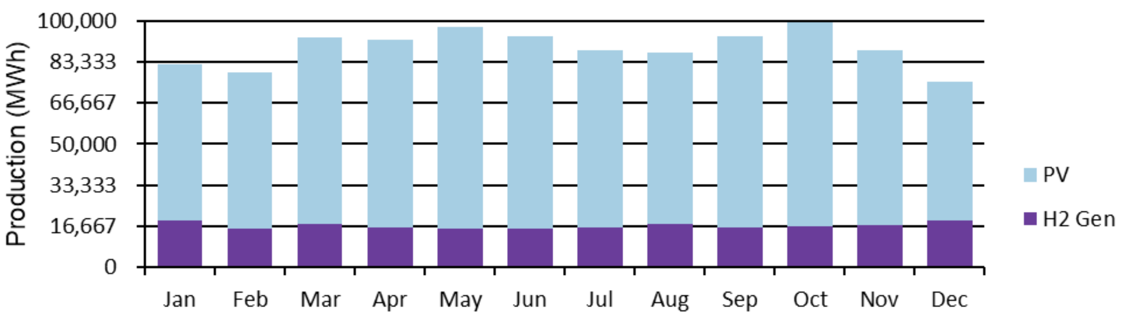


Figure 4. 5: Electrical Production from Model-1 for Plant-2

Generic flat plate PV			
Capacity Rating	531,251 kW	Total Production	866,659,328 kW
Investing Cost	$186M	Maintenance Cost	5,312,506 $/yr
Specific Yield	1,631 kWh/kW	LCOE	0.0218 $/kWh
PV Penetration	291 %		
Auto size Genset (Stored Hydrogen)			
Capacity	73,000 kW	Generator Fuel	Stored Hydrogen
Operational Life	2.24 yr	Generator Fuel Price	1.00 $/kg
Capital Cost	$29.2M	Maintenance Cost	4,891,730 $/yr
Fuel Consumption	16,230,199 kg	Electrical Production	202,583,520 kWh/yr
Hours of Operation	6,701 hrs/yr	Marginal Generation Cost	0 $/kWh
Fixed Generation Cost	2,677 $/hr		
System Converter			
Capacity	58,303 kW	Hours of Operation	8,760 hrs/yr
Normal Output	33,999 kW	Energy Out	297,831,008 kWh/yr
Lowest Output	1,638 kW	Energy In	313,506,304 kWh/yr
Optimal Output	58,303 kW	Losses	15,675,315 kWh/yr
Potential Factor	58.3 %		
Electrolyzer			
Initial Capital	$500M	Operating Expenses	40,000,000 $/yr
Rated Capacity	5,000,000 kW	Capacity Factor	1.73 %
Total Input Energy	755,736,576 kWh/yr	Total Production	16,285,591 kg/yr
Hours of Operation	4,164 hr/yr	Specific Consumption	46.4 kWh/kg
Minimum Output	0 kg/hr	Maximum Output	10,766 kg/hr
Hydrogen Tank			
Hydrogen Storage Capacity	10,000,000 kg	Energy Storage Capacity	333,333,344 kWh
Content at Beginning of Year	1,000,000 kg	Content at End of Year	1,055,392 kg
Tank Autonomy	9,804 hr		

4.3.2 Model-2 Results:

A generator with a capacity of 69,000 kW provides the electricity required by the Kalar Kahar Plant of Bestway Cement Ltd. The annual running energy expenses are $76.8M.

4.3.2.1 Electrical Production

With a peak power of 62330 kW, this microgrid uses 815830 kWh each day. The following generating sources power the electrical load in the system as suggested.

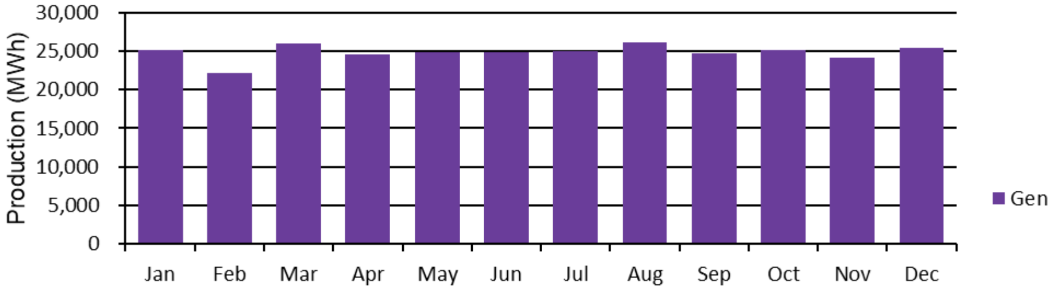


Figure 4. 6: Electrical Production from Model-2 for Plant-2

Auto size Genset (Diesel)			
Capacity	69,000 kW	Generator Fuel	Diesel
Operational Life	1.71 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$27.6M	Maintenance Cost	6,044,400 $/yr
Fuel Consumption	79,217,952 L	Electrical Production	298,130,592 kWh/yr
Hours of Operation	8,760 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	3,239 $/hr		

4.3.3 Model-3 Results:

1,795,492 kW of PV and 1,155,763 kWh of battery capacity are used to power the Kalar Kahar Plant of Bestway Cement Ltd. Your annual operational energy expenses are presently $263M.

4.3.3.1 Electrical Production

This microgrid has a peak power of 62330 kW and needs 815308 kWh per day. The following generating sources support the electrical load in the proposed system.

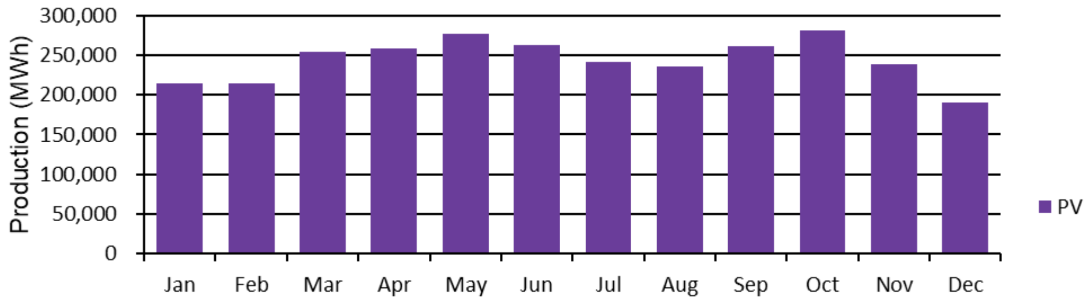


Figure 4. 7: Electrical Production from Model-3 for Plant-2

Generic flat plate PV			
Capacity Rating	1,795,492 kW	Total Production	2,929,087,488 kW
Investing Cost	$628M	Maintenance Cost	17,954,916 $/yr
Specific Yield	1,631 kWh/kW	LCOE	0.0218 $/kWh
PV Penetration	983 %		
Generic 1kWh Lead Acid			
Rated Capacity	1,155,763 kWh	Expected Life	5.17 yr
Annual Throughput	178,540,656 kWh/yr	Capital Costs	$5.08B
Maintenance Cost	9,238,712 $/yr	Losses	39,884,196 kWh/yr
Autonomy	20.4 hr		
System Converter			
Capacity	218,465 kW	Hours of Operation	8,757 hrs/yr
Normal Output	33,978 kW	Energy Out	297,647,008 kWh/yr
Lowest Output	0 kW	Energy In	313,312,640 kWh/yr
Optimal Output	62,330 kW	Losses	15,665,632 kWh/yr
Potential Factor	15.6 %		

4.3.4 Model-4 Results

A generator with a capacity of 69,000 kW supplies the electricity required by the Kalar Kahar Plant of Bestway Cement Ltd. The annual running costs for energy are $76.8M.

4.3.4.1 Electrical Production

This microgrid has a peak power of 62330 kW and needs 815830 kWh per day. The following generating sources support the electrical load in the proposed system.

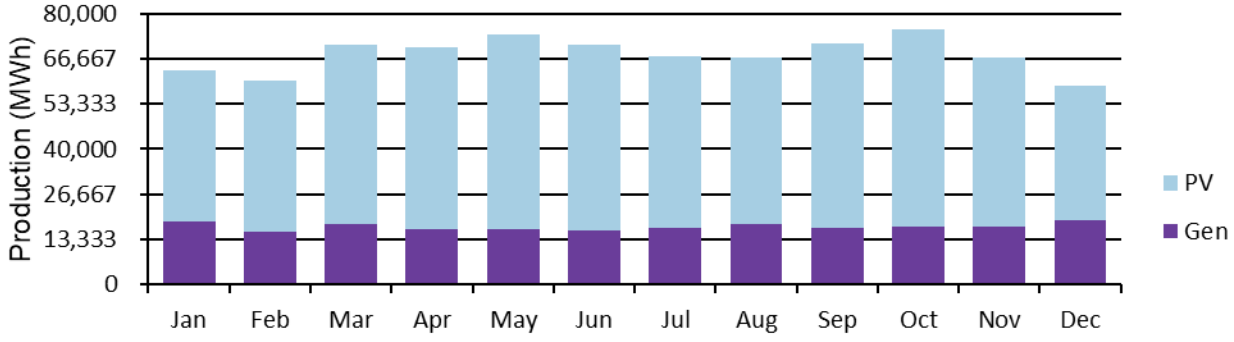


Figure 4. 8: Electrical Production from Model-4 for Plant-2

Generic flat plate PV			
Capacity Rating	374,000 kW	Total Production	610,128,192 kW
Investing Cost	$131M	Maintenance Cost	3,740,004 $/yr
Specific Yield	1,631 kWh/kW	LCOE	0.0218 $/kWh
PV Penetration	205 %		
Auto Size Genset (Diesel)			
Capacity	69,000 kW	Generator Fuel	Diesel
Operational Life	2.03 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$27.6M	Maintenance Cost	5,095,650 $/yr
Fuel Consumption	55,922,996 L	Electrical Production	205,310,592 kWh/yr
Hours of Operation	7,385 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	3,239 $/hr		
System Converter			
Capacity	54,539 kW	Hours of Operation	4,361 hrs/yr
Normal Output	10,586 kW	Energy Out	92,736,648 kWh/yr
Lowest Output	0 kW	Energy In	97,617,528 kWh/yr
Optimal Output	49,178 kW	Losses	4,880,876 kWh/yr
Potential Factor	19.4 %		

4.3.5 Models Evalution:

Model-1

	Base System	Proposed System
Net Present Cost	$2.89B	$2.89B
CAPEX	$743M	$743M
OPEX	$156M	$156M
LCOE (per kWh)	$0.706	$0.706
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	16,230,200	16,230,200

Model-2

	Base System	Proposed System
Net Present Cost	$1.08B	$1.08B
CAPEX	$27.6M	$27.6M
OPEX	$76.8M	$76.8M
LCOE (per kWh)	$0.265	$0.265
CO2 Emitted (kg/yr)	207,362,100	207,362,100
Fuel Consumption (L/yr)	79,217,950	79,217,950

Model-3

	Base System	Proposed System
Net Present Cost	$9.38B	$9.38B
CAPEX	$5.78B	$5.78B
OPEX	$263M	$263M
LCOE (per kWh)	$2.30	$2.30
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	0	0

Model-4

	Base System	Proposed System
Net Present Cost	$1.08B	$1.01B
CAPEX	$27.6M	$175M
OPEX	$76.8M	$61.1M
LCOE (per kWh)	$0.265	$0.248
CO2 Emitted (kg/yr)	207,362,100	146,384,900
Fuel Consumption (L/yr)	79,217,950	55,923,000

4.4 Bestway Cement Limited, Farooqia Plant

4.4.1 Model-1 Results:

582,751 kW of PV and 79,000 kW of generator capacity are used to provide Bestway Cement Ltd.'s Farooqia Plant's electricity demands. The annual running costs for energy are $158M.

4.4.1.1 Electrical Production

This microgrid has a max power of 588573 kW and needs 3144966 kWh per day. The following generating sources support the electrical load in the proposed system.

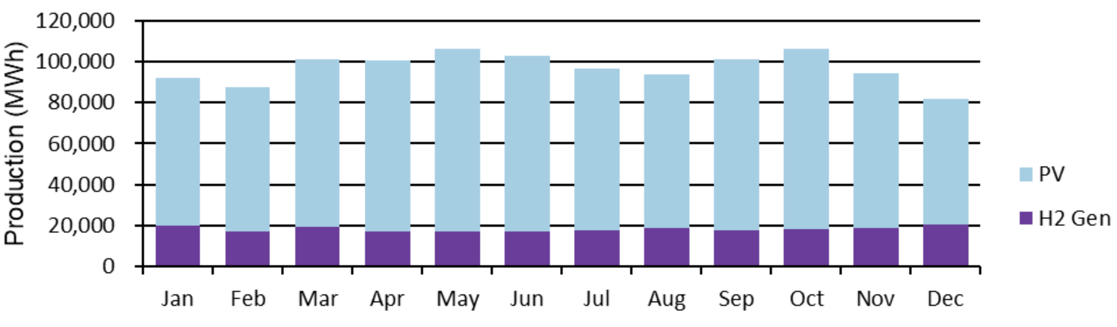


Figure 4. 9: Electrical Production from Model-1 for Plant-3

Generic flat plate PV			
Capacity Rating	582,751 kW	Total Production	944,352,192 kW
Investing Cost	$204M	Maintenance Cost	5,827,506 $/yr
Specific Yield	1,621 kWh/kW	LCOE	0.0219 $/kWh
PV Penetration	291 %		
Auto size Genset (Stored Hydrogen)			
Capacity	79,000 kW	Generator Fuel	Stored Hydrogen
Operational Life	2.24 yr	Generator Fuel Price	1.00 $/kg
Capital Cost	$31.6M	Maintenance Cost	5,298,530 $/yr
Fuel Consumption	17,639,338 kg	Electrical Production	220,283,552 kWh/yr
Hours of Operation	6,707 hrs/yr	Marginal Generation Cost	0 $/kWh
Fixed Generation Cost	2,897 $/hr		
System Converter			
Capacity	62,266 kW	Hours of Operation	8,760 hrs/yr
Normal Output	36,998 kW	Energy Out	324,098,848 kWh/yr
Lowest Output	1,783 kW	Energy In	341,156,672 kWh/yr
Optimal Output	62,266 kW	Losses	17,057,834 kWh/yr
Potential Factor	59.4 %		
Electrolyzer			
Initial Capital	$500M	Operating Expenses	40,000,000 $/yr
Rated Capacity	5,000,000 kW	Capacity Factor	1.88 %
Total Input Energy	823,479,104 kWh/yr	Total Production	17,745,394 kg/yr
Hours of Operation	4,150 hr/yr	Specific Consumption	46.4 kWh/kg
Minimum Output	0 kg/hr	Maximum Output	11,882 kg/hr
Hydrogen Tank			
Hydrogen Storage Capacity	10,000,000 kg	Energy Storage Capacity	333,333,344 kWh
Content at Beginning of Year	1,000,000 kg	Content at End of Year	1,106,057 kg
Tank Autonomy	9,009 hr		

4.4.2 Model-2 Results:

75,000 kW of generating capacity is used to meet the electricity demands of the Farooqia Plant of Bestway Cement Ltd. Your annual operational energy expenses are presently $83.5M.

4.4.2.1 Electrical Production

To supply the Farooqia Plant of Bestway Cement Ltd. with the power it needs, a generating capacity of 75,000 kW is utilised. Your current yearly operating energy costs are $83.5M.

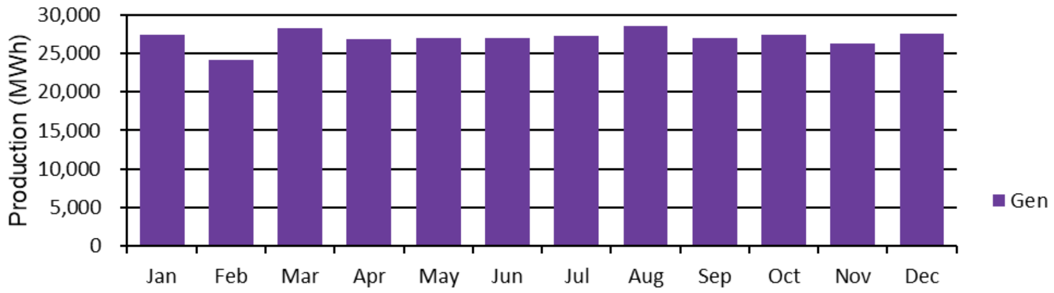


Figure 4. 10: Electrical Production from Model-2 for Plant-3

Auto size Genset (Diesel)			
Capacity	75,000 kW	Generator Fuel	Diesel
Operational Life	1.71 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$30.0M	Maintenance Cost	6,570,000 $/yr
Fuel Consumption	86,195,824 L	Electrical Production	324,433,632 kWh/yr
Hours of Operation	8,760 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	3,520 $/hr		

4.4.3 Model-3 Results:

With 1,953,917 kW of PV and 1,257,741 kWh of battery capacity, Bestway Cement limited, Farooqia Plant's energy demands are fully satisfied. Right now, your annual running energy expenses are $287M.

4.4.3.1 Electrical Production

This microgrid has a maximum capacity of 67829 kW and needs 887261 kWh per day. The following generating sources support the electrical load in the proposed system.

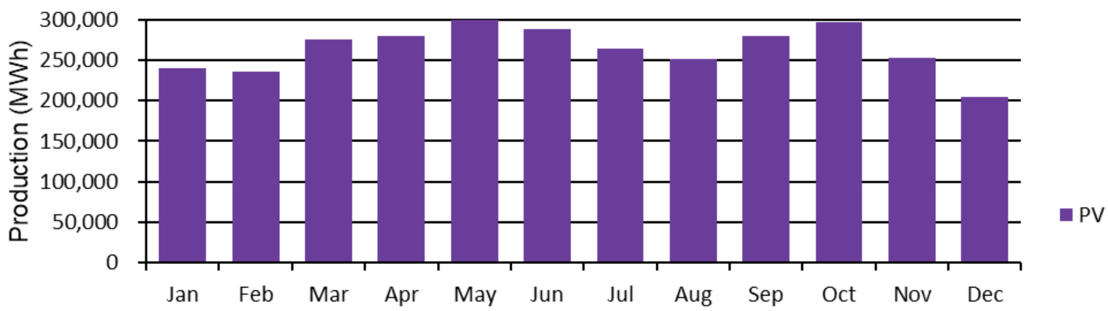


Figure 4. 11: Electrical Production from Model-3 for Plant-3

Generic flat plate PV			
Capacity Rating	1,953,917 kW	Total Production	3,166,338,816 kW
Investing Cost	$684M	Maintenance Cost	19,539,172 $/yr
Specific Yield	1,621 kWh/kW	LCOE	0.0208 $/kWh
PV Penetration	977 %		
Generic 1kWh Lead Acid			
Rated Capacity	1,257,741 kWh	Expected Life	5.17 yr
Annual Throughput	194,283,792 kWh/yr	Capital Costs	$5.53B
Maintenance Cost	10,053,888 $/yr	Losses	43,400,940 kWh/yr
Autonomy	20.4 hr		
System Converter			
Capacity	237,742 kW	Hours of Operation	8,760 hrs/yr
Normal Output	36,976 kW	Energy Out	323,913,824 kWh/yr
Lowest Output	0 kW	Energy In	340,961,920 kWh/yr
Optimal Output	67,829 kW	Losses	17,048,096 kWh/yr
Potential Factor	15.6 %		

4.4.4 Model-4 Results

The electric necessities Bestway Cement Ltd Frooqia are met with 75,000 kW of generator limit. Your working expenses for energy are presently $83.5M each year.

4.4.4.1 Electrical Production

This microgrid requires 887815 kWh/day and has a pinnacle of 67829 kW. In the proposed framework, the accompanying age sources serve the electrical burden.

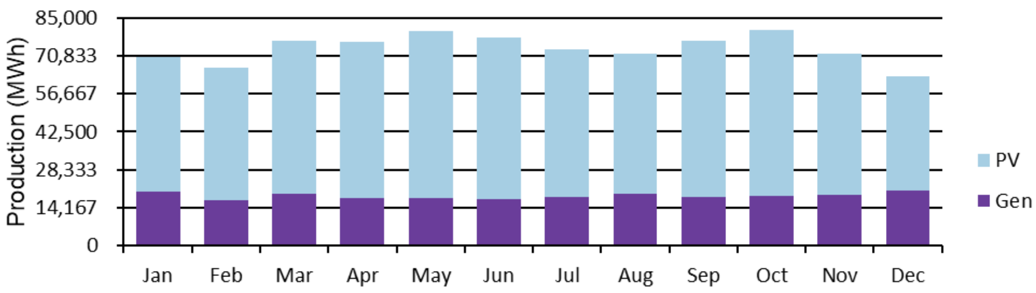


Figure 4. 12: Electrical Production from Model-4 for Plant-3

Generic flat plate PV			
Capacity Rating	407,000 kW	Total Production	659,547,584 kW
Investing Cost	$142M	Maintenance Cost	4,070,004 $/yr
Specific Yield	1,621 kWh/kW	LCOE	0.0219 $/kWh
PV Penetration	203 %		
Auto Size Genset (Diesel)			
Capacity	75,000 kW	Generator Fuel	Diesel
Operational Life	2.02 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$30.0M	Maintenance Cost	5,559,750 $/yr
Fuel Consumption	60,995,220 L	Electrical Production	223,920,336 kWh/yr
Hours of Operation	7,413 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	3,520 $/hr		
System Converter			
Capacity	57,232 kW	Hours of Operation	4,357 hrs/yr
Normal Output	11,464 kW	Energy Out	100,425,224 kWh/yr
Lowest Output	0 kW	Energy In	105,710,760 kWh/yr
Optimal Output	51,807 kW	Losses	5,285,538 kWh/yr
Potential Factor	20.0 %		

4.4.5 Models Evaluation:

Model-1

	Base System	Proposed System
Net Present Cost	$2.94B	$2.94B
CAPEX	$764M	$764M
OPEX	$158M	$158M
LCOE (per kWh)	$0.660	$0.660
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	17,639,340	17,639,340

Model-2

	Base System	Proposed System
Net Present Cost	$1.18B	$1.18B
CAPEX	$30.0M	$30.0M
OPEX	$83.5M	$83.5M
LCOE (per kWh)	$0.264	$0.264
CO2 Emitted (kg/yr)	225,627,500	225,627,500
Fuel Consumption (L/yr)	86,195,820	86,195,820

Model-3

	Base System	Proposed System
Net Present Cost	$10.5B	$10.5B
CAPEX	$6.28B	$6.28B
OPEX	$287M	$287M
LCOE (per kWh)	$2.20	$2.20
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	0	0

Model-4

	Base System	Proposed System
Net Present Cost	$1.18B	$1.10B
CAPEX	$30.0M	$190M
OPEX	$83.5M	$66.6M
LCOE (per kWh)	$0.264	$0.248
CO2 Emitted (kg/yr)	225,627,500	159,662,000
Fuel Consumption (L/yr)	86,195,820	60,995,220

4.5 Bestway Cement Limited, Hattar Plant

4.5.1 Model-1 Results:

The electric requirements of Bestway Cement ltd, Hattar Plant are met with 283,501 kW of PV and 39,000 kW of generator limit. Your working expenses for energy are as of now $146M each year.

4.5.1.1 Electrical Production

With a peak power of 286317 kW, this microgrid uses 1531019 kWh each day. The accompanying age sources support the electrical burden in the suggested framework.

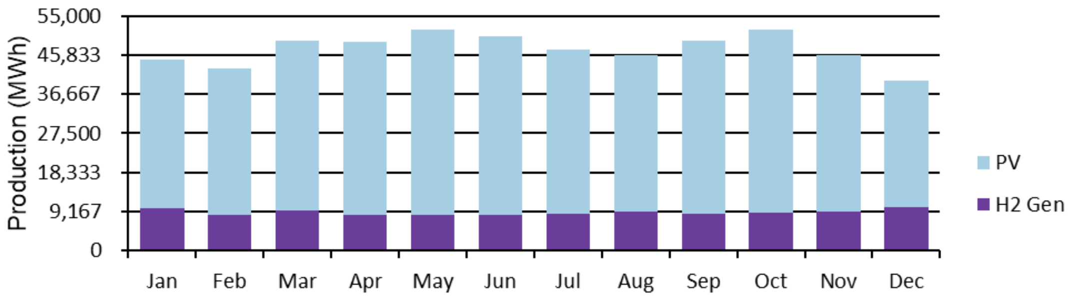


Figure 4. 13: Electrical Production from Model-1 for Plant-4

Generic flat plate PV			
Capacity Rating	283,501 kW	Total Production	459,500,992 kW
Investing Cost	$99.2M	Maintenance Cost	2,835,006 $/yr
Specific Yield	1,621 kWh/kW	LCOE	0.0219 $/kWh
PV Penetration	291 %		
Auto size Genset (Stored Hydrogen)			
Capacity	39,000 kW	Generator Fuel	Stored Hydrogen
Operational Life	2.24 yr	Generator Fuel Price	1.00 $/kg
Capital Cost	$15.6M	Maintenance Cost	2,614,950 $/yr
Fuel Consumption	8,617,734 kg	Electrical Production	107,456,224 kWh/yr
Hours of Operation	6,705 hrs/yr	Marginal Generation Cost	0 $/kWh
Fixed Generation Cost	1,430 $/hr		
System Converter			
Capacity	30,292 kW	Hours of Operation	8,760 hrs/yr
Normal Output	17,999 kW	Energy Out	157,669,712 kWh/yr
Lowest Output	867 kW	Energy In	165,968,112 kWh/yr
Optimal Output	30,292 kW	Losses	8,298,406 kWh/yr
Potential Factor	59.4 %		
Electrolyzer			
Rated Capacity	5,000,000 kW	Capacity Factor	0.915 %
Total Input Energy	400,989,088 kWh/yr	Total Production	8,641,032 kg/yr
Hours of Operation	4,160 hr/yr	Specific Consumption	46.4 kWh/kg
Minimum Output	0 kg/hr	Maximum Output	5,781 kg/hr
Hydrogen Tank			
Hydrogen Storage Capacity	10,000,000 kg	Energy Storage Capacity	333,333,344 kWh
Content at Beginning of Year	1,000,000 kg	Content at End of Year	1,023,299 kg
Tank Autonomy	18,519 hr		

4.5.2 Model-2 Results:

With a maximum generating power of 37,000 kW, the electrical needs of the Bestway Cement Ltd. Hattar Plant are satisfied. Currently, $40.8 million is spent annually on your working energy costs.

4.5.2.1 Electrical Production

This microgrid requires 431910 kWh/day and has a peak of 32998 kW. In the proposed system, the following generation sources serve the electrical load.

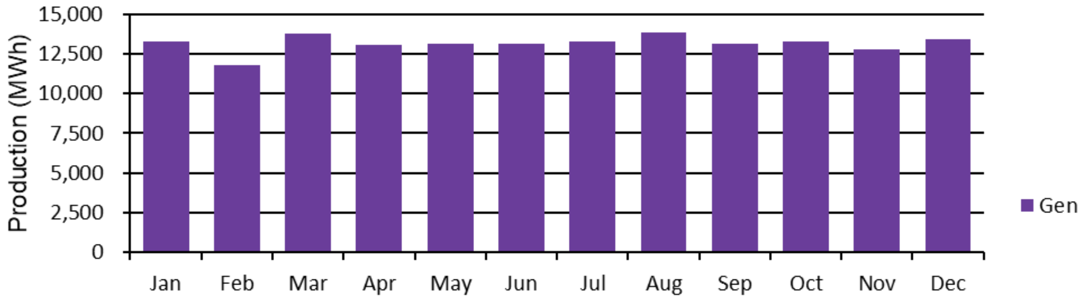


Figure 4. 14: Electrical Production from Model-2 for Plant-4

Auto size Genset (Diesel)			
Capacity	37,000 kW	Generator Fuel	Diesel
Operational Life	1.71 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$14.8M	Maintenance Cost	3,241,200 $/yr
Fuel Consumption	42,002,772 L	Electrical Production	157,848,192 kWh/yr
Hours of Operation	8,760 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	1,737 $/hr		

4.5.3 Model-3 Results:

The electric necessities of Bestway Cement ltd, Hattar Plant are met with 950,555 kW of PV and 611,875 kWh of battery limit. Your working expenses for energy are at present $139M each year.

4.5.3.1 Electrical Production

With a peak power of 32998 kW, this microgrid needs 431640 kWh each day. The accompanying age sources in the suggested structure help with the electrical load.

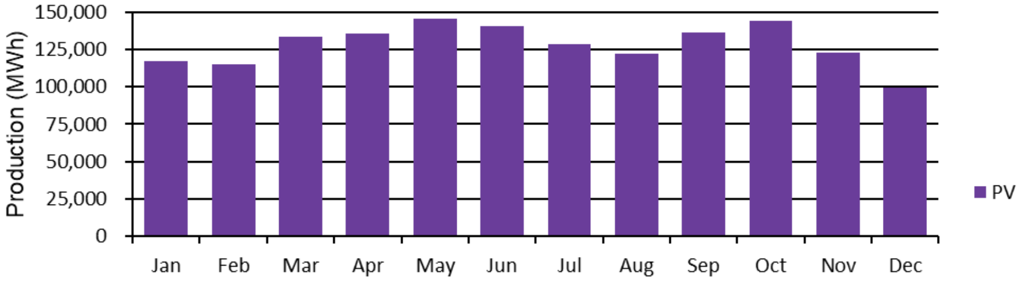


Figure 4. 15: Electrical Production from Model-3 for Plant-4

Generic flat plate PV			
Capacity Rating	950,555 kW	Total Production	1,540,670,720 kW
Investing Cost	$333M	Maintenance Cost	9,505,555 $/yr
Specific Yield	1,621 kWh/kW	LCOE	0.0219 $/kWh
PV Penetration	977 %		
Generic 1kWh Lead Acid			
Rated Capacity	611,875 kWh	Expected Life	5.17 yr
Annual Throughput	94,538,080 kWh/yr	Capital Costs	$2.69B
Maintenance Cost	4,891,088 $/yr	Losses	21,118,812 kWh/yr
Autonomy	20.4 hr		
System Converter			
Capacity	115,659 kW	Hours of Operation	8,760 hrs/yr
Normal Output	17,989 kW	Energy Out	157,579,744 kWh/yr
Lowest Output	0 kW	Energy In	165,873,408 kWh/yr
Optimal Output	32,998 kW	Losses	8,293,670 kWh/yr
Potential Factor	15.6 %		

4.5.4 Model-4 Results

37,000 kW of generator power is sufficient to meet the electrical needs of the Hattar Plant of Bestway Cement Ltd. Your functioning costs for energy are correct now $40.8M every year.

4.5.4.1 Electrical Production

With a peak power of 32998 kW, this microgrid uses 431910 kWh every day. The accompanying age sources support the electrical burden in the suggested framework.

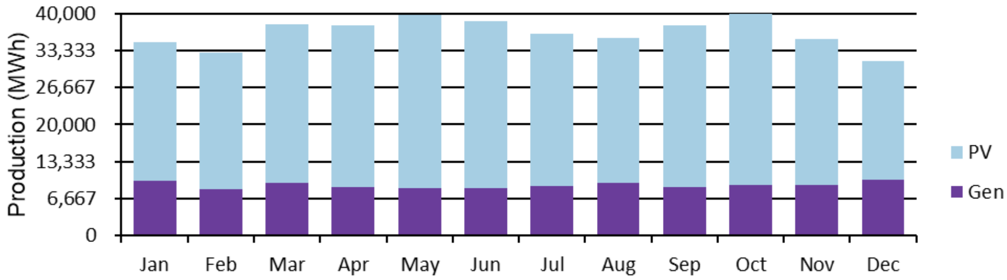


Figure 4. 16: Electrical Production from Model-4 for Plant-4

Generic flat plate PV			
Capacity Rating	203,538 kW	Total Production	329,897,088 kW
Investing Cost	$71.2M	Maintenance Cost	2,035,383 $/yr
Specific Yield	1,621 kWh/kW	LCOE	0.0219 $/kWh
PV Penetration	209 %		
Auto size Genset (Diesel)			
Capacity	37,000 kW	Generator Fuel	Diesel
Operational Life	2.04 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$14.8M	Maintenance Cost	2,716,170 $/yr
Fuel Consumption	29,603,310 L	Electrical Production	108,566,368 kWh/yr
Hours of Operation	7,341 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	1,737 $/hr		
System Converter			
Capacity	28,229 kW	Hours of Operation	4,359 hrs/yr
Normal Output	5,620 kW	Energy Out	49,233,316 kWh/yr
Lowest Output	0 kW	Energy In	51,824,544 kWh/yr
Optimal Output	25,608 kW	Losses	2,591,227 kWh/yr
Potential Factor	19.9 %		

4.5.5 Models Evaluation:

Model-1

	Base System	Proposed System
Net Present Cost	$2.63B	$2.63B
CAPEX	$634M	$634M
OPEX	$146M	$146M
LCOE (per kWh)	$1.22	$1.22
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	8,617,734	8,617,734

Model-2

	Base System	Proposed System
Net Present Cost	$575M	$575M
CAPEX	$14.8M	$14.8M
OPEX	$40.8M	$40.8M
LCOE (per kWh)	$0.266	$0.266
CO2 Emitted (kg/yr)	109,947,100	109,947,100
Fuel Consumption (L/yr)	42,002,770	42,002,770

Model-3

	Base System	Proposed System
Net Present Cost	$4.97B	$4.97B
CAPEX	$3.06B	$3.06B
OPEX	$139M	$139M
LCOE (per kWh)	$2.30	$2.30
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	0	0

Model-4

	Base System	Proposed System
Net Present Cost	$575M	$540M
CAPEX	$14.8M	$94.5M
OPEX	$40.8M	$32.5M
LCOE (per kWh)	$0.266	$0.249
CO2 Emitted (kg/yr)	109,947,100	77,490,060
Fuel Consumption (L/yr)	42,002,770	29,603,310

4.6 DG Cement Limited, Chakwal Plant

4.6.1 Model 1 Results:

The electric necessities of DG Cement Limited, Chakwal Plant are met with 480,501 kW of PV and 66,000 kW of generator limit. Your working expenses for energy are presently $154M each year.

4.6.1.1 Electrical Production

With a peak power of 484266 kW, this microgrid uses 2639175 kWh every day. The accompanying age sources support the electrical burden in the suggested framework.

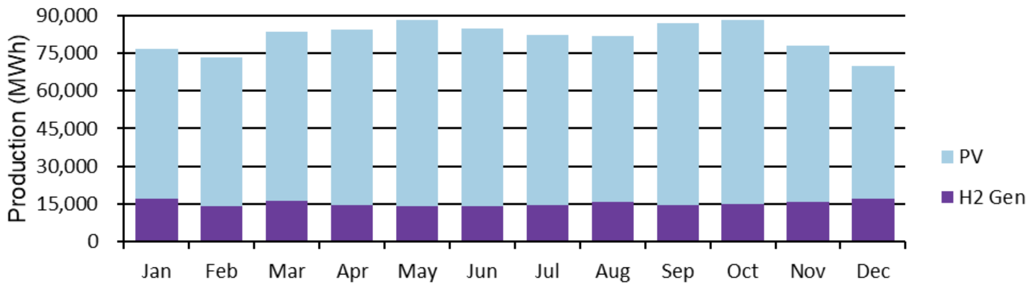


Figure 4. 17: Electrical Production from Model-1 for Plant-5

Generic flat plate PV			
Capacity Rating	480,501 kW	Total Production	793,220,800 kW
Investing Cost	$168M	Maintenance Cost	4,805,006 $/yr
Specific Yield	1,651 kWh/kW	LCOE	0.0215 $/kWh
PV Penetration	292 %		
Auto size Genset (Stored Hydrogen)			
Capacity	66,000 kW	Generator Fuel	Stored Hydrogen
Operational Life	2.24 yr	Generator Fuel Price	1.00 $/kg
Capital Cost	$26.4M	Maintenance Cost	4,414,080 $/yr
Fuel Consumption	14,737,830 kg	Electrical Production	184,129,088 kWh/yr
Hours of Operation	6,688 hrs/yr	Marginal Generation Cost	0 $/kWh
Fixed Generation Cost	2,420 $/hr		
System Converter			
Capacity	52,354 kW	Hours of Operation	8,760 hrs/yr
Normal Output	30,998 kW	Energy Out	271,544,672 kWh/yr
Lowest Output	1,494 kW	Energy In	285,836,512 kWh/yr
Optimal Output	52,354 kW	Losses	14,291,825 kWh/yr
Potential Factor	59.2 %		
Electrolyzer			
Initial Capital	$500M	Operating Expenses	40,000,000 $/yr
Rated Capacity	5,000,000 kW	Capacity Factor	1.58 %
Total Input Energy	691,513,408 kWh/yr	Total Production	14,901,626 kg/yr
Hours of Operation	4,160 hr/yr	Specific Consumption	46.4 kWh/kg
Minimum Output	0 kg/hr	Maximum Output	9,790 kg/hr
Hydrogen Tank			
Hydrogen Storage Capacity	10,000,000 kg	Energy Storage Capacity	333,333,344 kWh
Content at Beginning of Year	1,000,000 kg	Content at End of Year	1,163,797 kg
Tank Autonomy	10,753 hr		

4.6.2 Model-2 Results:

With 63,000 kW of generator capacity, DG Cement Limited's Chakwal Plant's electrical needs are satisfied. Your working expenses for energy are presently $70.0M each year.

4.6.2.1 Electrical Production

With a peak power of 56830 kW, this microgrid uses 743845 kWh every day. The accompanying age sources support the electrical burden in the suggested framework.

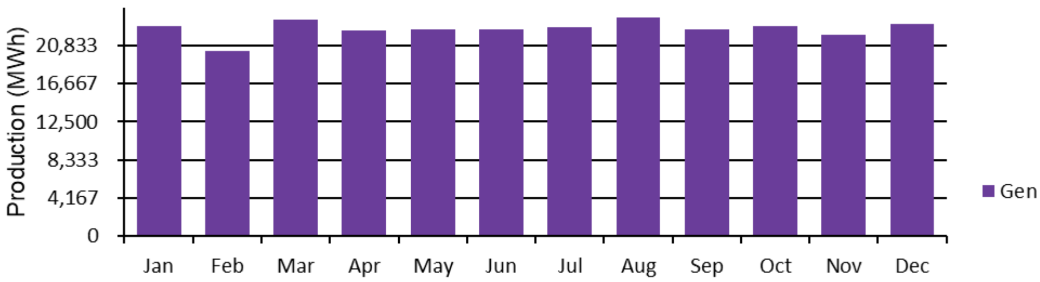


Figure 4. 18: Electrical Production from Model-2 for Plant-5

Auto size Genset (Diesel)			
Capacity	63,000 kW	Generator Fuel	Diesel
Operational Life	1.71 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$25.2M	Maintenance Cost	5,518,800 $/yr
Fuel Consumption	72,240,096 L	Electrical Production	271,827,584 kWh/yr
Hours of Operation	8,760 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	2,957 $/hr		

4.6.3 Model-3 Results:

The electric necessities of DG Cement Limited, Chakwal Plant are met with 1,283,201 kW of PV and 1,077,846 kWh of battery limit. Your working expenses for energy are presently $236M each year.

4.6.3.1 Electrical Production

With a peak power of 56830 kW, this microgrid uses 743277 kWh each day. The accompanying age sources support the electrical burden in the suggested framework.

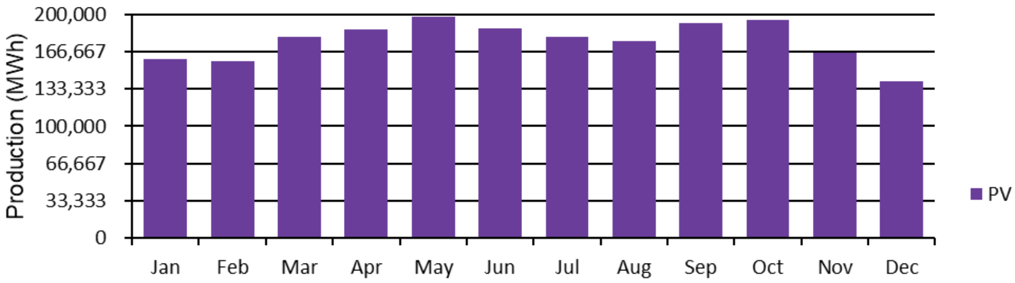


Figure 4. 19: Electrical Production from Model-3 for Plant-5

Generic flat plate PV			
Capacity Rating	1,283,201 kW	Total Production	2,118,335,232 kW
Investing Cost	$449M	Maintenance Cost	12,832,007 $/yr
Specific Yield	1,651 kWh/kW	LCOE	0.0215 $/kWh
PV Penetration	780 %		
Generic 1kWh Lead Acid			
Rated Capacity	1,077,846 kWh	Expected Life	5.26 yr
Annual Throughput	163,862,640 kWh/yr	Capital Costs	$4.74B
Maintenance Cost	8,615,872 $/yr	Losses	36,604,948 kWh/yr
Autonomy	20.9 hr		
System Converter			
Capacity	144,614 kW	Hours of Operation	8,760 hrs/yr
Normal Output	30,976 kW	Energy Out	271,348,640 kWh/yr
Lowest Output	0 kW	Energy In	285,630,144 kWh/yr
Optimal Output	56,830 kW	Losses	14,281,508 kWh/yr
Potential Factor	21.4 %		

4.6.4 Model-4 Results

The electric necessities of, DG Cement Chakwal, Pakistan are met with is 63,000 kW generator limit. Your working expenses for energy are at present $70.0M each year.

4.6.4.1 Electrical Production

With a peak power of 56830 kW, this microgrid uses 743845 kWh every day. The accompanying age sources support the electrical burden in the suggested framework.

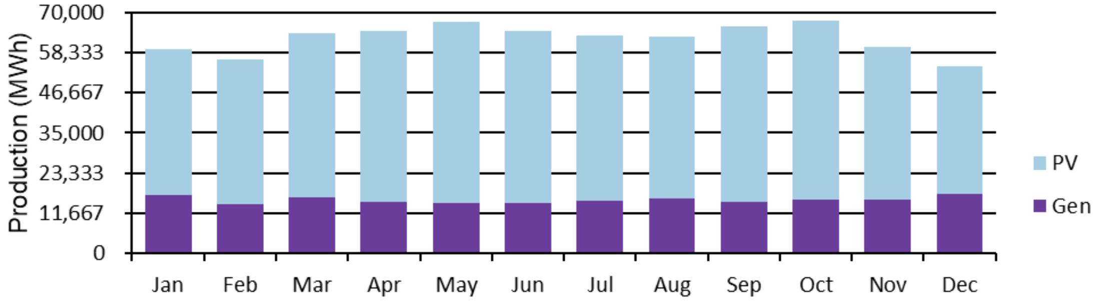


Figure 4. 20: Electrical Production from Model-4 for Plant-5

Generic flat plate PV			
Capacity Rating	341,000 kW	Total Production	562,930,880 kW
Investing Cost	$119M	Maintenance Cost	3,410,004 $/yr
Specific Yield	1,651 kWh/kW	LCOE	0.0215 $/kWh
PV Penetration	207 %		
Auto size Genset (Diesel)			
Capacity	63,000 kW	Generator Fuel	Diesel
Operational Life	2.04 yr	Generator Fuel Price	0.700 $/L
Capital Cost	$25.2M	Maintenance Cost	4,638,690 $/yr
Fuel Consumption	50,880,456 L	Electrical Production	186,782,256 kWh/yr
Hours of Operation	7,363 hrs/yr	Marginal Generation Cost	0.165 $/kWh
Fixed Generation Cost	2,957 $/hr		
System Converter			
Capability	49,727 kW	Hours of Operation	4,356 hrs/yr
Normal Output	9,700 kW	Energy Out	84,969,920 kWh/yr
Lowest Output	0 kW	Energy In	89,442,024 kWh/yr
Optimal Output	44,839 kW	Losses	4,472,101 kWh/yr
Potential Factor	19.5 %		

4.6.5 Models Evaluation:

Model-1

	Base System	Proposed System
Net Present Cost	$2.83B	$2.83B
CAPEX	$720M	$720M
OPEX	$154M	$154M
LCOE (per kWh)	$0.760	$0.760
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	14,737,830	14,737,830

Model-2

	Base System	Proposed System
Net Present Cost	$987M	$987M
CAPEX	$25.2M	$25.2M
OPEX	$70.0M	$70.0M
LCOE (per kWh)	$0.265	$0.265
CO2 Emitted (kg/yr)	189,096,800	189,096,800
Fuel Consumption (L/yr)	72,240,100	72,240,100

Model-3

	Base System	Proposed System
Net Present Cost	$8.48B	$8.48B
CAPEX	$5.23B	$5.23B
OPEX	$236M	$236M
LCOE (per kWh)	$2.28	$2.28
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	0	0

Model-4

	Base System	Proposed System
Net Present Cost	$987M	$923M
CAPEX	$25.2M	$159M
OPEX	$70.0M	$55.6M
LCOE (per kWh)	$0.265	$0.248
CO2 Emitted (kg/yr)	189,096,800	133,185,400
Fuel Consumption (L/yr)	72,240,100	50,880,460

4.7 Sensitivity Analysis

For a specialized and financial investigation of the practicable models are made sense of utilizing the sensitivity analysis. For that reason, the system's adjustable characteristics Discounted rate, Inflation rate, and load have been selected as controllable variables for each of the five locations being targeted. Every year, the government changes its policies, which causes uncertainty in the inflation rate. Construction policies allow the cement industry to grow its production capacity, which increases the load, which is why the load is considered a sensitivity parameter. By choosing the load to be 30, 60, 90, 130, and 150 % of the initial load, the inflation rate to be 10, 14, and 18%, and the discounted rate to be 25, 35, and 50 %, sensitivity analysis is carried out. Figure 4.21 displays the simulation's results.

The government policies allow the cement industry to increase its production capacity by 31% [42]. According to [43] 16 cement industries are under construction , which will increases the load demand of cement industries. which is why the load is considered a sensitivity parameter. Inflation are the key factor which impact the employment rates, taxes and government polices so it’s very important to follow the inflation rate [44]. Since December 2008, the inflation rate has increased [45]. HMS techno-economic analysis can be demonstrate using sensitivity analysis. For that reason, the system's adjustable characteristics Discounted rate, Inflation rate, and load have been selected as controllable variables for each of the five locations being targeted. By choosing the load to be 30 %, 60 %, 90 %, 130 %, and 150 % of the initial load, the inflation rate to be 10 %, 14 %, and 18 %, and the discounted rate to be 25 %, 35 %, and 50 %, sensitivity analysis is carried out. Figure 11 displays the simulation's results.

Model-2 and 4 NPC will be at least US$42.6 million by taking on 30% of Plant-1's load, with inflation and the discounted rate set at 50% and 14%, respectively. Model-2 and 4 NPC will be at least US$85.3 million by taking on 60% of Plant-1's load, with inflation and the discounted rate at 50% and 14%, respectively. Model-2 and 4 NPC will cost at least US$128 million if Plant-1's load is considered, with inflation and the discounted rate coming in at 50% and 14%, respectively. Models-2 and 4 NPC will cost at least US$185 million by taking on 130% of Plant-1's load, with inflation and discounted rates of 50% and 14%, respectively. Models-2 and 4 NPC will cost at least US$213 million if Plant-1's load is considered, with inflation and the discounted rate set at 50% and 14%, respectively.

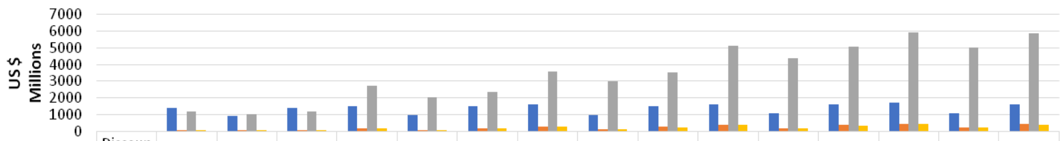
Model-2 and 4 NPC will be at least US$80.9 million by taking on 30% of Plant-2's load, with inflation and the discounted rate set at 50% and 14%, respectively. Model-2 and 4 NPC will be at least US$162 million by taking on 60% of Plant-2's load, with inflation and the discounted rate at 50% and 14%, respectively. Model-2 and 4 NPC will cost at least US$241 million if Plant-2's load is considered, with inflation and the discounted rate coming in at 50% and 14%, respectively. Models-2 and 4 NPC will cost at least US$ 349 million by taking on 130% of Plant-2's load, with inflation and discounted rates of 50% and 14%, respectively. Models-2 and 4 NPC will cost at least US$413 million if Plant-2's load is considered, with inflation and the discounted rate set at 50% and 14%, respectively.

Model-2 and 4 NPC will be at least US$88.3 million by taking on 30% of Plant-3's load, with inflation and the discounted rate set at 50% and 14%, respectively. Model-2 and 4 NPC will be at least US$175 million by taking on 60% of Plant-3's load, with inflation and the discounted rate at 50% and 14%, respectively. Model-2 and 4 NPC will cost at least US$263 million if Plant-3's load is considered, with inflation and the discounted rate coming in at 50% and 14%, respectively. Models-2 and 4 NPC will cost at least US$378 million by taking on 130% of Plant-3's load, with inflation and discounted rates of 50% and 14%, respectively. Models-2 and 4 NPC will cost at least US$450 million if Plant-3's load is considered, with inflation and the discounted rate set at 50% and 14%, respectively.

Model-2 and 4 NPC will be at least US$42.6 million by taking on 30% of Plant-4's load, with inflation and the discounted rate set at 50% and 14%, respectively. Model-2 and 4 NPC will be at least US$85.3 million by taking on 60% of Plant-4's load, with inflation and the discounted rate at 50% and 14%, respectively. Model-2 NPC will cost at least US$128 million if Plant-4's load is considered, with inflation and the discounted rate coming in at 50% and 14%, respectively. Models-2 NPC will cost at least US$185 million by taking on 130% of Plant-4's load, with inflation and discounted rates of 50% and 14%, respectively. Models-2 NPC will cost at least US$213 million if Plant-4's load is considered, with inflation and the discounted rate set at 50% and 14%, respectively.

Model-2 and 4 NPC will be at least US$73.5 million by taking on 30% of Plant-5's load, with inflation and the discounted rate set at 50% and 14%, respectively. Model-2 and 4 NPC will be at least US$147 million by taking on 60% of Plant-5's load, with inflation and the discounted rate at 50% and 14%, respectively. Model-2 and 4 NPC will cost at least US$221 million if Plant-5's load is considered, with inflation and the discounted rate coming in at 50% and 14%, respectively. Models-2 and 4 NPC will cost at least US$318 million by taking on 130% of Plant-5's load, with inflation and discounted rates of 50% and 14%, respectively. Models-2 and 4 NPC will cost at least US$366 million if Plant-5's load is considered, with inflation and the discounted rate set at 50% and 14%, respectively.

Askari Cement Limited, Wah Plant

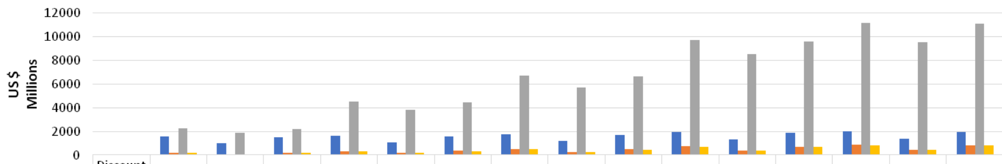


	Discounted Rate(%)	25	50	35	25	50	35	25	50	35	25	50	35	25	50	35
	Inflation Rate(%)	10	14	18	10	14	18	10	14	18	10	14	18	10	14	18
	Load (KW)	5400	5400	5400	10800	10800	10800	16200	16200	16200	23400	23400	23400	27000	27000	27000
Model 1	0	1400	946	1400	1500	993	1500	1600	1000	1500	1600	1100	1600	1700	1100	1600
Model 2	0	90.2	42.6	86.1	180	85.3	172	271	128	258	392	185	374	451	213	431
Model 3	0	1190	1010	1170	2730	2020	2340	3560	3020	3520	5140	4370	5080	5940	5040	5860
Model 4	0	85.9	42.6	82.2	172	85.3	164	258	128	249	374	185	357	430	213	411

Model 1 Model 2 Model 3 Model 4

(a)

Bestway Cement Limited, Kalar Kahar Plant

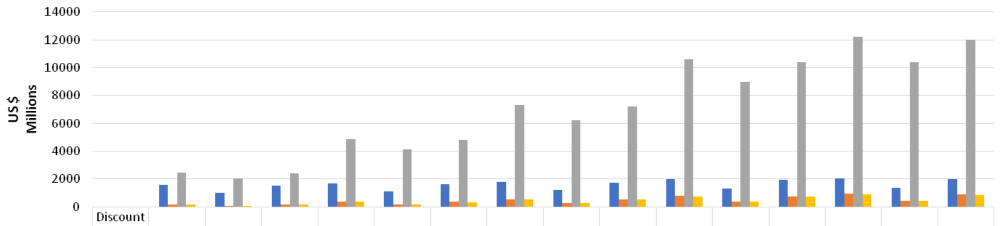


	Discounted Rate(%)	25	50	35	25	50	35	25	50	35	25	50	35	25	50	35
	Inflation Rate(%)	10	14	18	10	14	18	10	14	18	10	14	18	10	14	18
	Load (KW)	10200	10200	10200	20400	20400	20400	30600	30600	30600	44200	44200	44200	51000	51000	51000
Model 1	0	1540	988	1490	1660	1080	1600	1770	1170	1720	1930	1290	1870	2010	1350	1950
Model 2	0	171	80.9	163	342	162	377	510	241	487	738	349	705	872	413	833
Model 3	0	2240	1900	2210	4490	3810	4430	6730	5710	6640	9720	8520	9590	11200	9520	11113
Model 4	0	163	80.9	156	326	162	312	485	241	464	703	349	672	834	413	798

Model 1 Model 2 Model 3 Model 4

(b)

Bestway Cement Limited, Farooqia Plant

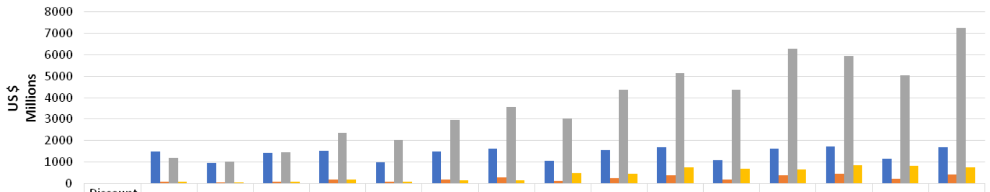


	Discounted Rate(%)	25	50	35	25	50	35	25	50	35	25	50	35	25	50	35
	Inflation Rate(%)	10	14	18	10	14	18	10	14	18	10	14	18	10	14	18
	Load (KW)	11100	11100	11100	22200	22200	22200	33300	33300	33300	48100	48100	48100	55500	55500	55500
Model 1	0	1550	996	1500	1680	1090	1630	1800	1190	1750	1990	1330	1940	2060	1390	2000
Model 2	0	187	88.3	178	370	175	353	557	263	532	800	378	764	950	450	907
Model 3	0	2440	2070	2410	4880	4140	4820	7320	6220	7230	10600	8980	10400	12200	10400	12000
Model 4	0	178	88.3	170	352	175	337	530	263	508	762	378	729	909	450	870

Model 1 Model 2 Model 3 Model 4

(c)

Bestway Cement Limited, Hattar Plant

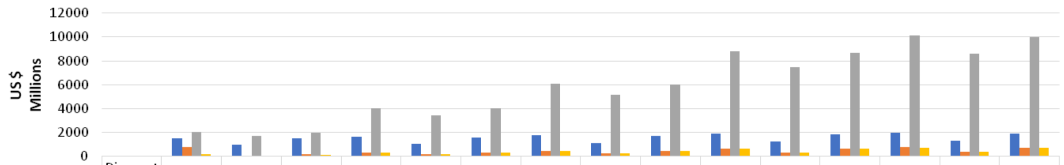


	Discounted Rate(%)	25	50	35	25	50	35	25	50	35	25	50	35	25	50	35
	Inflation Rate(%)	10	14	18	10	14	18	10	14	18	10	14	18	10	14	18
	Load (KW)	5400	5400	5400	10800	10800	10800	16200	16200	16200	23400	23400	23400	27000	27000	27000
Model 1	0	1480	946	1440	1540	993	1500	1610	1040	1560	1690	1100	1640	1730	1140	1680
Model 2	0	90.2	42.6	86.1	180	85.3	172	271	128	258	392	185	374	451	213	431
Model 3	0	1190	1010	1450	2370	2020	2960	3560	3020	4360	5140	4370	6290	5940	5040	7260
Model 4	0	85.9	42.6	82.2	172	85.3	164	154	484	459	745	702	665	857	807	765

Model 1 Model 2 Model 3 Model 4

(d)

DG Cement Limited, Chakwal Plant



	Discounted Rate(%)	25	50	35	25	50	35	25	50	35	25	50	35	25	50	35
	Inflation Rate(%)	10	14	18	10	14	18	10	14	18	10	14	18	10	14	18
	Load (KW)	9300	9300	9300	18600	18600	18600	27900	27900	27900	40300	40300	40300	46500	46500	46500
Model 1	0	1530	979	1480	1630	1060	1580	1740	1140	1690	1880	1250	1820	1950	1300	1890
Model 2	0	756	73.5	149	311	147	297	467	221	446	673	318	643	775	366	740
Model 3	0	2030	1720	2000	4050	3440	4000	6080	5160	6000	8780	7460	8670	10100	8610	10000
Model 4	0	148	73.5	142	296	147	283	444	221	445	670	318	612	736	366	704

Model 1 Model 2 Model 3 Model 4

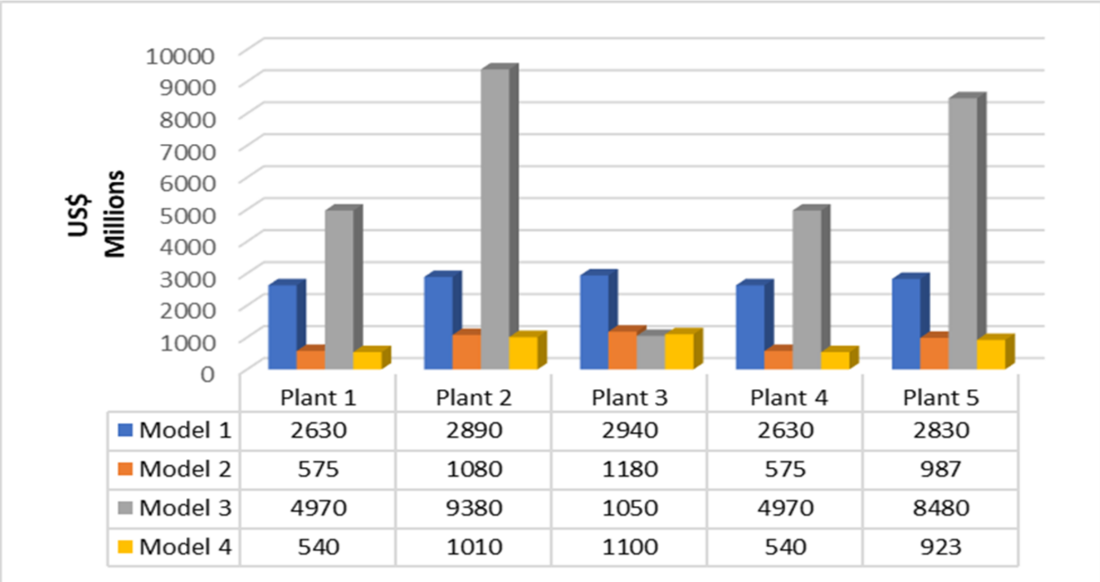
(e)

Figure 4. 21: Sensitivity analysis for Plants (a) 1, (b) 2, (c) 3, (d) 4, and (e) 5

4.8 Cost Analysis

NPC for Plant-1 from Models-1 and 2 is US$2630M and US$575M, but Models-3 and Model-4 have corresponding Net NPCs of US$4970M and US$540M. NPC for Model-1 at Plant-2 is US$2890M, whereas NPC for Models-2, 3, and 4 is US$1080M, US$9380M, and US$1010M, respectively. Models-1, 2, 3, and 4 for Plant-3 NPC cost US$2940M, US$1180M, US$1050M, and US$1100M, respectively. Model-1 of Plant-4 NPC costs US$2630M, whereas Models-2, 3, and 4 NPC cost US$575M, US$4970M, and US$540M, respectively.

The NPC for Plant 5 is shown in Figure 4.22 as US$2830M for Model-1, US$1,87M for Model-2, US$8,480M for Model-3, and US$923M for Model-4.



	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5
Model 1	2630	2890	2940	2630	2830
Model 2	575	1080	1180	575	987
Model 3	4970	9380	1050	4970	8480
Model 4	540	1010	1100	540	923

Figure 4. 22: Comparison of the net present costs for Plants 1, 2, 3, 4, and 5

4.9 GHG Emissions

Energy generation results in the release of various dangerous gas emissions, depending on the sources used. The total quantity of carbon dioxide produced per kWh is determined by the energy sources utilized to produce the energy and varies depending on the fuel used, which is why it varies second by second from year to year. In addition, every kWh results in the production of 1.34 g of nitrogen oxides and 2.74 g of carbon dioxide. The sustainable mixture model-1 or model-3 does not contain any harmful gases, such as nitrogen oxides (NO), sulphur dioxide (SO2), carbon monoxide (CO), unburned hydrocarbons (UHCs), or carbon dioxide (CO2).

The ecology won't be harmed by the dangerous gases used in this sustainable hybrid model. The generator in the hybrid models 2 and 4 produces dangerous gases. The generator in this type has been restricted to only provide the absolute minimal amount of energy during crises to minimize harmful gas emissions and environmental harm. The Model-1 fuel cell's output has been constrained to reduce dangerous gas production. A fuel cell produces no carbon dioxide emissions. Warm water is all that is left in the end. It thus produces less pollution than Model-2 and Model-4. The values for these variables are shown in Figures 4.23–4.27.

	Model 1	Model 2	Model 3	Model 4
	Plant 1			
Carbon Dioxide	0	109,947,082	0	77,181,597
Carbon Monoxide	0	693,046	0	486,510
Unburned Hydrocarbons	0	30,242	0	21,230
Particulate Matter	0	4,200	0	2,949
Sulfur Dioxide	0	269,234	0	188,999
Nitrogen Oxides	0	651,043	0	457,025

Figure 4. 23: Model comparisons for Plant-1's GHG emissions

	Model 1	Model 2	Model 3	Model 4
	Plant 2			
Carbon Dioxide	0	207,362,097	0	146,384,868
Carbon Monoxide	0	1,307,096	0	922,729
Unburned Hydrocarbons	0	57,037	0	40,265
Particulate Matter	0	7,922	0	5,592
Sulfur Dioxide	0	507,781	0	358,462
Nitrogen Oxides	0	1,227,878	0	866,806

Figure 4. 24: Model comparisons for Plant-2's GHG emissions

	Model 1	Model 2	Model 3	Model 4
	Plant 3			
Carbon Dioxide	0	225,627,464	0	157,994,511
Carbon Monoxide	0	1,422,231	0	995,910
Unburned Hydrocarbons	0	62,061	0	43,458
Particulate Matter	0	8,620	0	6,036
Sulfur Dioxide	0	552,508	0	386,891
Nitrogen Oxides	0	1,336,035	0	935,552

Figure 4. 25: Model comparisons for Plant-3's GHG emissions

	Model 1	Model 2	Model 3	Model 4
	Plant 4			
Carbon Dioxide	0	109,947,082	0	77,490,066
Carbon Monoxide	0	693,046	0	488,455
Unburned Hydrocarbons	0	30,242	0	21,314
Particulate Matter	0	4,200	0	2,960
Sulfur Dioxide	0	269,234	0	189,755
Nitrogen Oxides	0	651,043	0	458,851

Figure 4. 26: Model comparisons for Plant-4's GHG emissions

Plant 5	Model 1	Model 2	Model 3	Model 4
Carbon Dioxide	0	189,096,752	0	133,185,441
Carbon Monoxide	0	1,191,962	0	839,528
Unburned Hydrocarbons	0	52,013	0	36,634
Particulate Matter	0	7,224	0	5,088
Sulfur Dioxide	0	463,053	0	326,140
Nitrogen Oxides	0	1,119,721	0	788,647

Figure 4. 27: Model comparisons for Plant-5's GHG emissions

CHAPTER 5

CONCLUSIONS

Diesel generators continue to dominate the market for electrical generators in off-grid isolated locations, which has increased greenhouse gas emissions (GHG). The use of environmentally friendly power advancements in off-grid hybrid energy schemes has led to increasing electrical energy production and consumption.

A comparison study of various hybrid micropower system approaches has been conducted to address the issue of power outages and emissions. Therefore, five cement plants are called Askari Cement Plant, Wah, Bestway Cement Limited's Kalar Kahar. Bestway Cement Limited in Farooqia. Bestway Cement Limited in Hattar and DG Cement Limited in Chakwal was considered for the Analysis. The results from the four different models which mainly concentrate on net present cost, initial project cost, and running costs, are examined using simulations and optimization. After looking at each model for the chosen sites, the following conclusions were made:

- Model-1 and Model-4 are the most optimal solutions for all plants in terms of GHG emissions with 0% emissions.
- Models 2 are the best in terms of initial costs.

The most optimal COE / NPC model for each of the chosen Plants is:

- The most practical and cost-effective option for the Askari Cement Plant in Wah is Model-4, with NPC of US$540M, COE of US$0.249/kWh, and operating cost of US$32.4M/year, and reduction of CO_2 emissions of 29.80%.
- The most cost-effective and practical model for Bestway Cement Limited, Kalar Kahar, is Model-4, with an NPC of US$ 1010M, COE of US$0.248/kWh, and operating costs of US$61.1M/year with a reduction of 29.40 % CO_2 Emission.

- NPC US$1100M for DG Cement Limited, Chakwal having LCOE US$0.248/KWh, Model-4 is the most feasible model. The Model-4's annual operating expenses are US$66.6 million, with a decrease in CO2 emissions of 29.97%.
- NPC US$540M for Bestway Cement Limited, Hattar having LCOE US$0.249/KWh, Model-4 is the most feasible model. The Model-4 has annual running expenses of $32.5 million and a reduction in CO2 emissions of 29.56 percent.
- NPC US$923M for DG Cement Limited, Chakwal having LCOE US$0.248/KWh, Model-4 is the most feasible model. The Model-4 reduces CO2 emissions by 29.56 percent while having annual running expenses of $55.6M.

5.1 Future Work

- Cost can be reduced either by adding more renewable Resources or by connecting to Grid.
- We can Use Block chain Energy Transaction System to purchase Energy from these Micro grids.
- These Micro grids can be act as a DG in smart grid System.

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