Article

Analyzing the Prospect of Hybrid Energy in the Cement Industry of Pakistan Using Homer Pro

Yasir Basheer [1], Asad Waqar [1,*], Saeed Mian Qaisar [2,3], Toqeer Ahmed [4], Nasim Ullah [5], Sattam Alotaibi [5 *]

1 Department of Electrical Engineering, Bahria School of Engineering and Applied Sciences, Bahria University, Islamabad 44000, Pakistan; 01-244202-021@student.bahria.edu.pk
2 College of Engineering, Effat University, Jeddah 22332, Saudi Arabia; sqaisar@effatuniversity.edu.sa
3 Communication and Signal Processing Lab, Energy and Technology Center, Effat University, Jeddah 22332, Saudi Arabia
4 Digital Pakistan Lab (DPL) and CureMD, School of Interdisciplinary Engineering and Sciences (SINES), National University of Science and Technology (NUST), 44000 Islamabad, Pakistan; toqeer.ahmed@iiu.edu.pk
5 Department of Electrical Engineering, College of Engineering, Taif University, Al-Hawiyah, Taif P.O. Box 888, Saudi Arabia; nasimullah@tu.edu.sa
* Correspondence: asadwaqar.buic@bahria.edu.pk (A.W.); srotaibi@tu.edu.sa (S.T.)

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.

Keywords: Cement Industry, Homer Pro Optimization, Techno-Economic Analysis, Sensitivity Analysis, Net Present Cost, Greenhouse Gas Emissions, Levelized Cost of Electricity

1 Introduction

Because of the increasing population and industrialization of the world, energy demand 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 (CO_2), which can be done by switching to cleaner energy sources [2]. Environmentally friendly power sources (RESs, for example, sun-oriented photovoltaic (PV), hydropower, geothermal, wind, and biomass, could offer serious expense choices, spotless and manageable energy to everybody, no matter what their geological area [3]. 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. HESS can provide more reliable,

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controllable, and economical frameworks than single energy sources [4]. The perfect planning and preparation of HES components may be the key concern in their execution. The microgrid may be enhanced on every level to provide the perfect operating conditions that allow for the fulfillment of 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. Figure 1 [5] shows the solar potential of Pakistan. 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

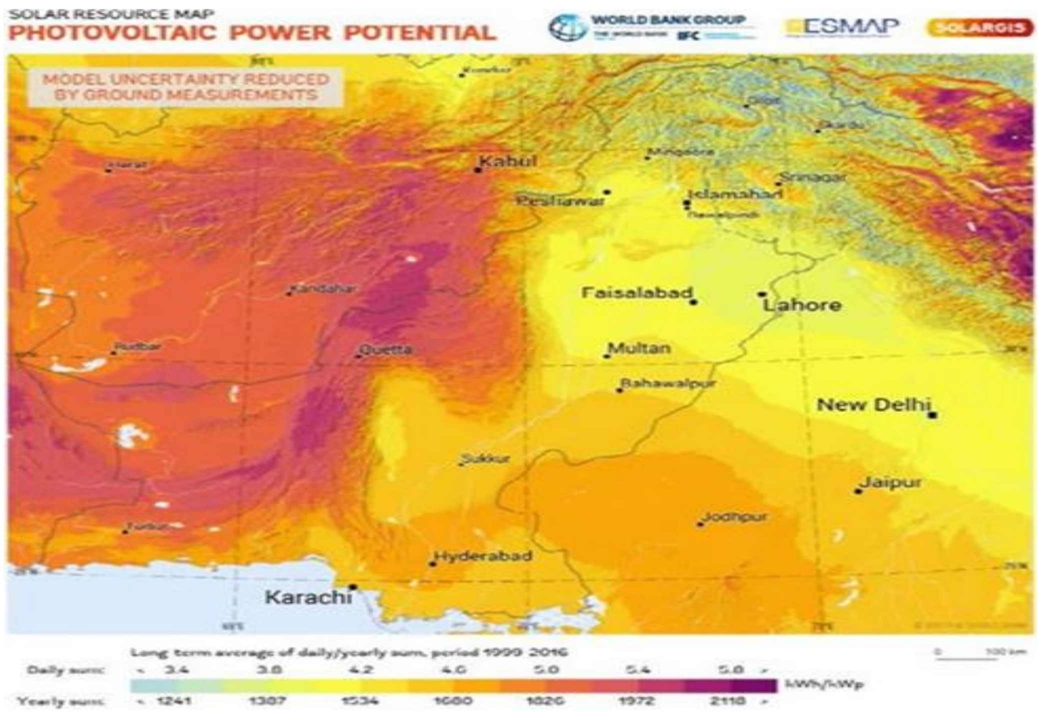

Figure 1. Solar potential map of Pakistan [5]

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 optimal HES estimate. Hemeida et al. [10] performed a review to look at the best strategy 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. A multiple-objective improvement model developed in [11] decides on the best setup for a PV/wind/diesel/battery crossover system. The framework's feasibility was supported by exploratory outcomes in real-world applications. HOMER, short for Hybrid Optimization of Multiple Energy Resources, was employed in [12] to investigate the feasibility of a sustainable PV/biomass combo system for meeting the power needs of a private site in Palestine, 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 mix conventional sources with cogeneration, PV, hydropower, wind turbines, 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, a dispatch procedure is a set of rules for the control of the dispatchable sources, such as the public framework, generator, and battery [21]. Load following (LF) and cycle charging are the two important default dispatch techniques in HOMER programming (CC). These methods select the most realistic configuration that can satisfy the power interest at each time step without taking the future burden profile or source circumstances into account. The generator behaves very differently under LF and CC dispatch strategies. In the LF technique, the generator just produces enough power to satisfy the electrical load, leaving the battery uncharged. The battery is charged throughout this procedure by RESs. However, to fulfill the power demand, the generator runs at full capacity and denies having additional power throughout 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] a PV/wind/miniature hydro/biogas/battery HES was explored using the LF approach multicriteria arranging to meet the demand for energy in a rural Tanzanian location. The

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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 the international airport in Egypt. The energy stream control between the components was ensured using the CC method. The findings gained demonstrated that the recommended HES is practical 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. The long-term research revealed that the most common setup, employs a PV, diesel generator, and battery HES under the LF method. In [27], From the technical and economical perspectives of the shock of a rural village in Nigeria, it was analyzed the system, which consists of a PV, wind turbine, hydropower, diesel generator, and battery. 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 financial analysis of a PV/diesel/battery HES for an educational facility in India. 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. An optimum HES design for the shock of a provincial area in Malawi was investigated in [29]. The energy transfer between the different framework elements and the heap was investigated using the CC technique. According to the findings, the NPC is negatively impacted by the project's lifespan variations in wind speed and diesel cost. In [30], the Designers of the framework assessed the technical, financial, and energy advantages of utilizing a PV, diesel engine, and battery to provide power to a particular location in Minya City, Egypt. The results show 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.

The use of HMS in the cement industry needs to take the load into serious consideration. Most studies make assumptions about load levels without considering in-depth research on plant improvement, inflation rate, and discounted rate characteristics. This study aims to design a HMS, cost-effective, and low-emission process for Pakistani cement industries while keeping this gap in mind. The project's main goal was to assess the proposed system's techno-economic viability in terms of actual implementation under local circumstances.

- This article aims to show the feasibility of implementing a HMS in cement industries considering objectives including NPC, LCOE and GHG emissions.
- The viability of implementing solar panels (PV system) together with the diesel generator is also studied in view of minimizing the objectives including NPC, LCOE and GHG emissions.
- Four different models are studied to find the optimal HMS.
- As per the authors best of knowledge it is a first study that deals with the implementation of HMS 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.

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Cement Plant-3: Bestway Cement Limited, Farooqia.
Cement Plant-4: Bestway Cement Limited, Hattar.
Cement Plant-5: DG Cement Limited, Chakwal.

2 Methodology

HMS was used in the design of this power-producing system. The approach system is shown in Figure 2.

- Data Collection like Load demand, component specifications, and meteorological data, such as solar irradiance data, are input into HOMER to optimize the microgrid system.
- 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, removes options that aren't optimal because they can't fulfill constraints, and then offers a list of optimal solutions and organizes them according to the optimization variable of choice (NPC).

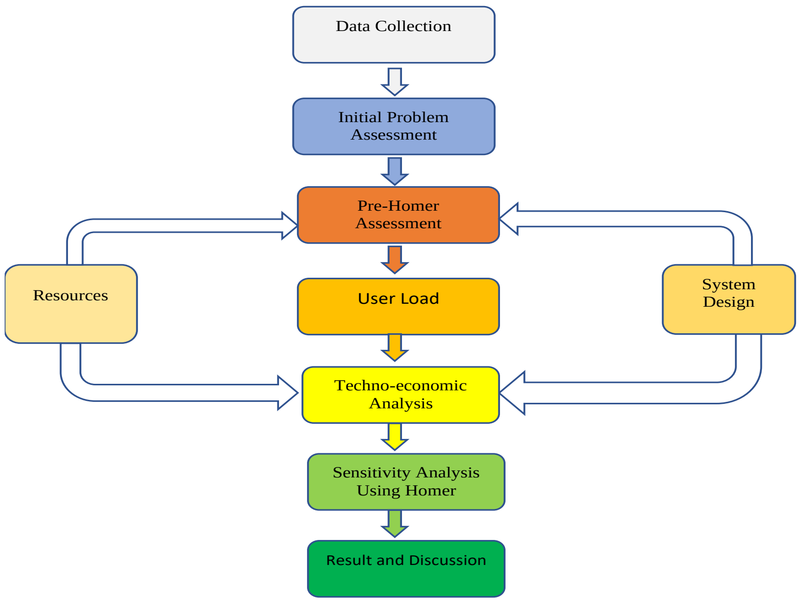

Figure 2. Methodology framework of the hybrid microgrid design

2.1 *Multi-Objective Analysis Using HOMER Pro*

Developed by the U.S. National Renewable Energy Laboratory, HOMER is an optimization tool (NREL). Additionally, HOMER enables users to evaluate various producing and storage unit configurations in terms of their technical and financial advantages. The user enters resource information into the HOMER, including average daily solar irradiation, the load profile to be supplied, the generating and storage units to be considered, and their costs. After that, for a year, the software calculates the hourly power balance for each arrangement. The optimal options are ordered according to the lowest total net current cost after all feasible configurations have been simulated, the impractical alternatives having been eliminated (TNPC).

The optimizer used by HOMER is based on derivative-free optimization. A modified grid search technique is employed by the optimization algorithm. While the algorithm looks for the best solution, the user provides several parameters (in the form of inputs) connected to the generating/storage units in a searchable grid. The HOMER first accepts input data in table form, after which it runs simulations on the data to determine every conceivable configuration [33]. These configurations are then examined to narrow down the ideal configuration while taking the objectives into account.

2.2 *Objective and Constraints*

The microgrid's ideal configuration is determined by several factors. The reduction of annual greenhouse gas (GHG) emissions, cost of generated energy, and total net present cost (TNPC) of the microgrid are a few of the various goals.

2.3 *Net Present Cost*

The net present cost of the combination framework is equal to the continuing value of the different costs the framework incurred throughout its stated 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:

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

Here, Cann, tot = Annualized cost. i = Interest rate (Annual). Rproj = Project lifetime. CRF (.) = Capital recovery factor.

2.2 *Levelized Cost of Energy*

It is stated as an average price per kilowatt-hour of power delivered by the predetermined shaped framework. To determine the optimal COE for a standalone system, HOMER uses the Equation (2) from [34]:

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

E_{prim} is the total primary load, Cann. tot is the annualized total cost, E_{def} is the total deferrable load, and E_{grid}, sales are the amount of energy sold to the grid (per year).

2.4 *Total Annualized Cost*

It is described as the amount that will happen yearly during the undertaking evaluation time 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.

2.5 *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 demand. The most practical and affordable solutions for each model are given, 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(a), it will have a PV module, hydrogen tank, converter, electrolyzer, and energy component.
- Model-2: As shown in Figure 3(b), it will only have a diesel generator.
- Model-3: As shown in Figure 3(c), it will have a PV module, converter, and battery framework.
- Model-4: As shown in Figure 3(d), it will have a diesel generator, PV module, and Converter.

2.5.1 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.

2.5.2 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 5-9, daily and seasonal load profiles are depicted. In Figure 4 Energy consumed per day is shown.

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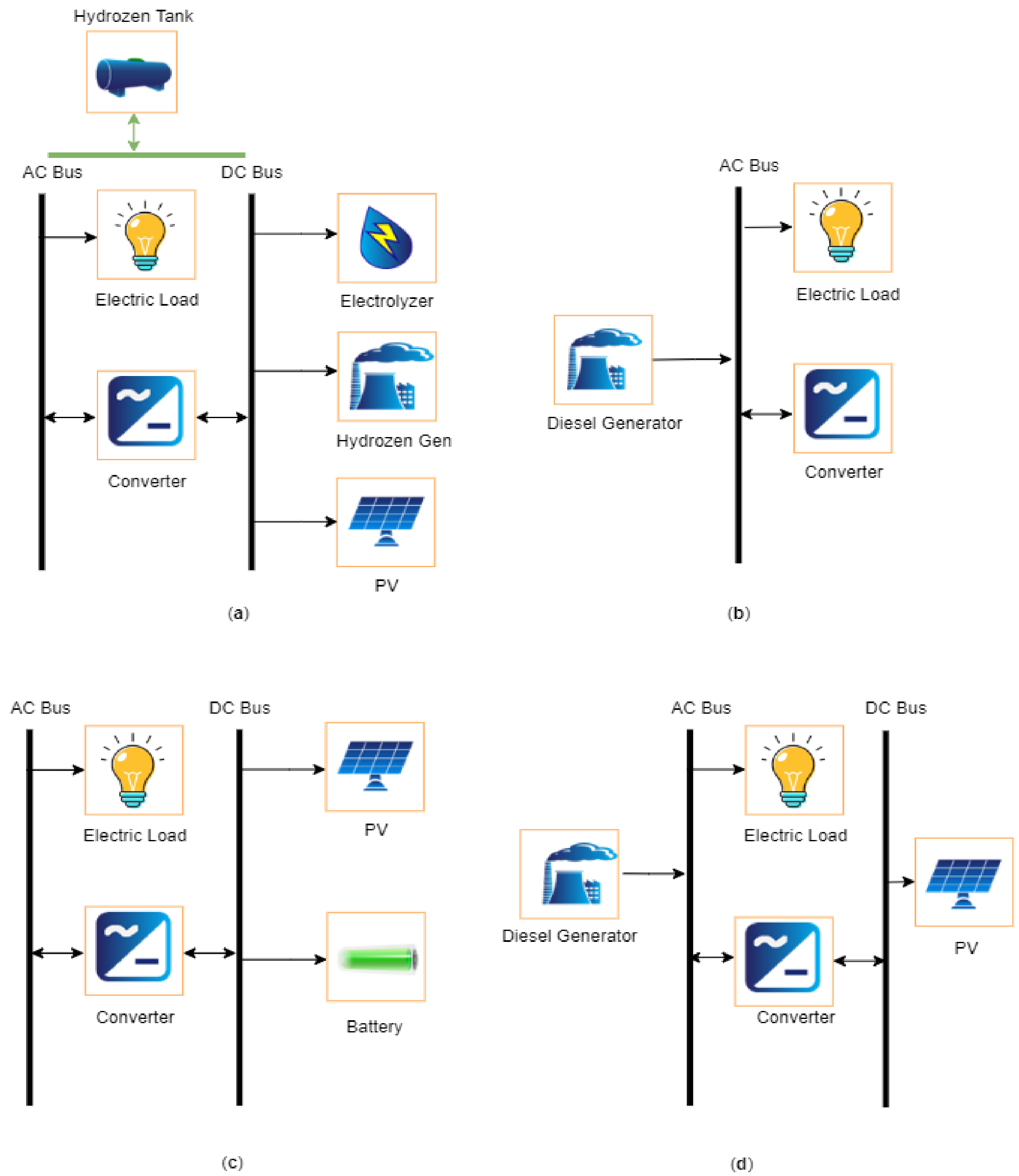

Figure 3. Schematic diagram of Models (**a**) Model-1 (**b**) Model-2 (**c**) Model-3 (**d**) Model-4

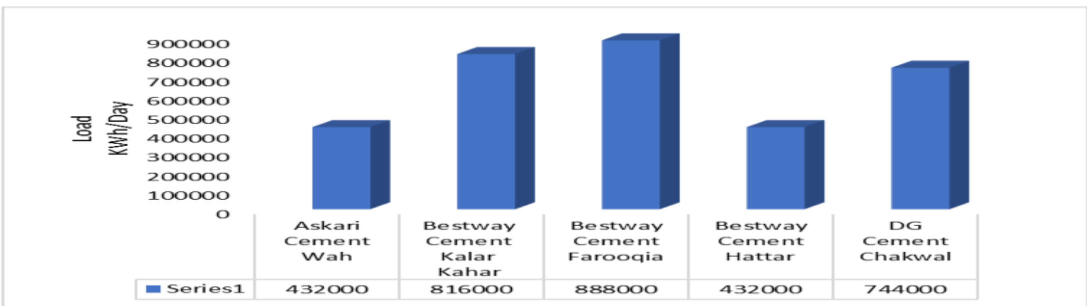

Figure 4. Daily Energy of the Plants

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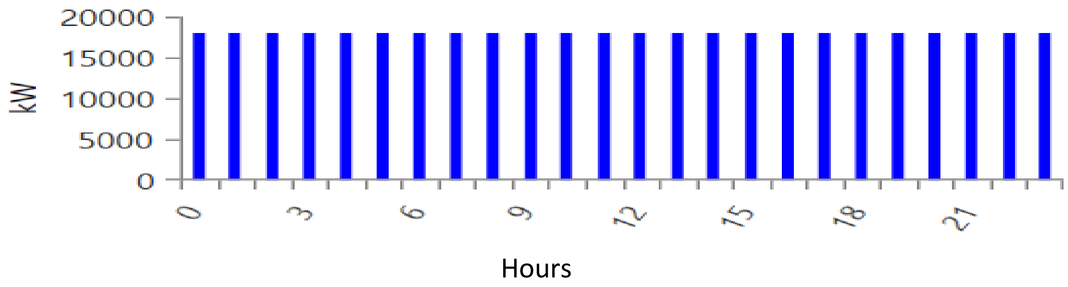

Fig. 5 Plant-1's Daily Load Profile

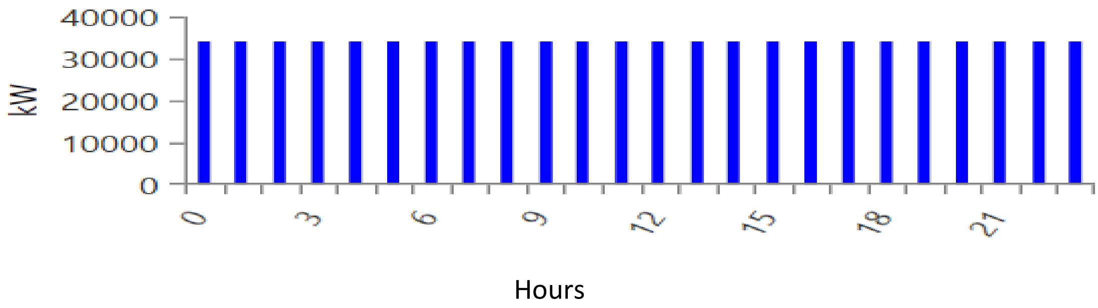

Fig. 6 Plant-2's Daily Load Profile

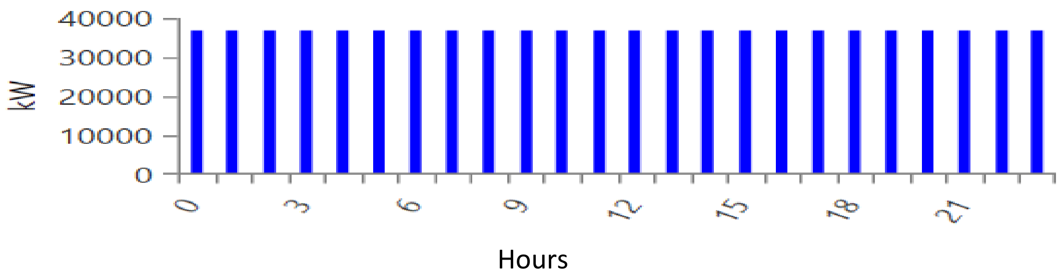

Fig. 7 Plant-3's Daily Load Profile

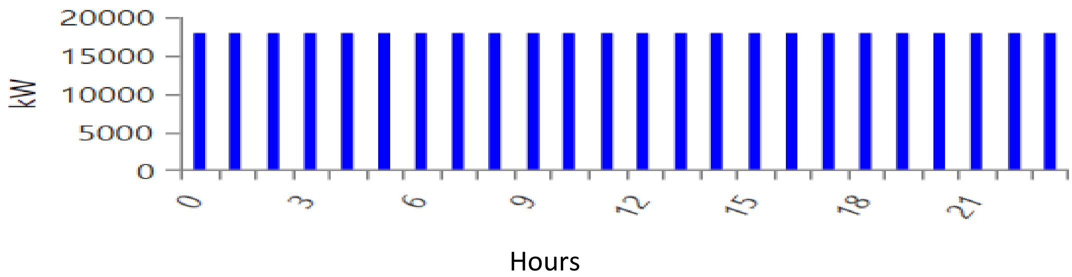

Fig. 8 Plant-4's Daily Load Profile

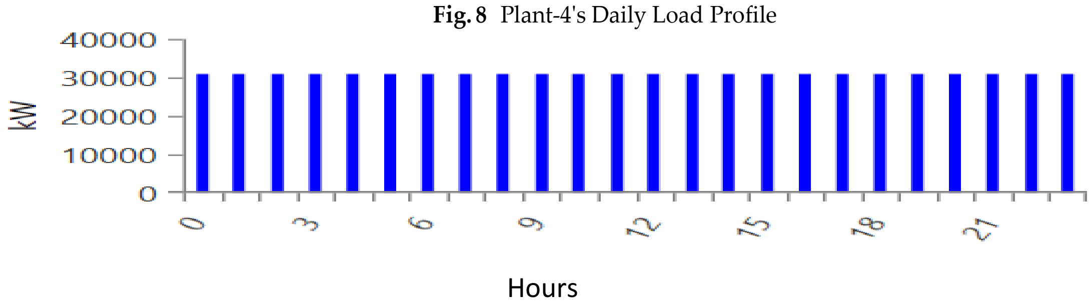

Figure 9. Plant-5's Daily Load Profile

2.5.3 Energy Resource Assessment

Information about the potential for energy resources depends largely on the location of the area. Data on the potential of wind and solar power are abundant in Pakistan. The geographic location of the prospective locations has been taken into account while estimating their resource potential

2.5.3.1 *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 sunlight-based radiation of Plant-1 to plant-5 are displayed in Table 1. The yearly typical temperature for Plant-1 is 22.85 C°. For Plant-2, the yearly normal temperature is 17.80 C°. For Plant-3, the yearly normal temperature is 22.75 C°. For Plant-4, the yearly normal temperature is 22.75 C°. For Plant-5, the yearly normal temperature is 24.21 C° 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 10 shows the annual daily radiation in kWh/m2/day. The yearly average radiations for Plants 1 and 2 are around 4.91, for Plants 3 and 4, they are 4.89, and for Plant 5, they are 5.027 kWh/m2/day. Pakistan's average daily solar radiation is 5.0 kWh/m2/day, 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, Worldweather-Online, and a book of maps that are oriented toward the sun [35].

2.6 *Microgrid Components*

The suggested systems' hybrid model is made up of many component kinds. Table 2 provides the component prices. The discussion of these elements follows.

2.6.1 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 rated capacity of one kW. 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%. 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} it is known as the nominal capacity of the group of photovoltaic solar panels in units of measurement (kW), IT is the total incident radiation on the rectangular surface of the solar panel (kWh/m2), IS consider it as a base value of 1000 W/m2 knowing that it is an ideal value of desirable irradiation, and f_{pv} is the reduction factor, which depends on factors like energy loss caused by long wiring distances, by splices or terminal connections, and unkempt wiring surfaces.

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Table 1. Average monthly values for solar (kWh/m²/day), wind (m/s).

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

Table 2. Components cost [5]

Components	Initial costUS$/kW	Replacement cost US$/kW	Operatingcost	Lifetime inyears
PV panel	350	350	10	25
Wind turbine	6000	5000	25	20
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

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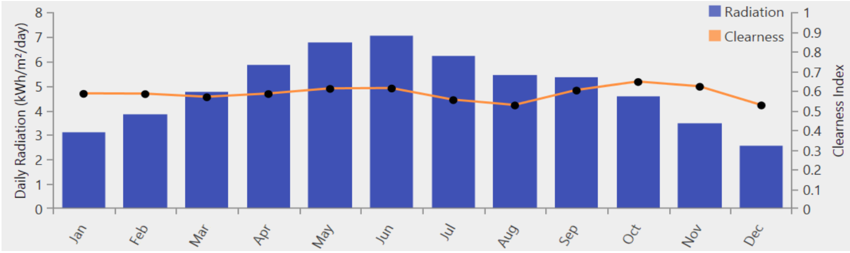
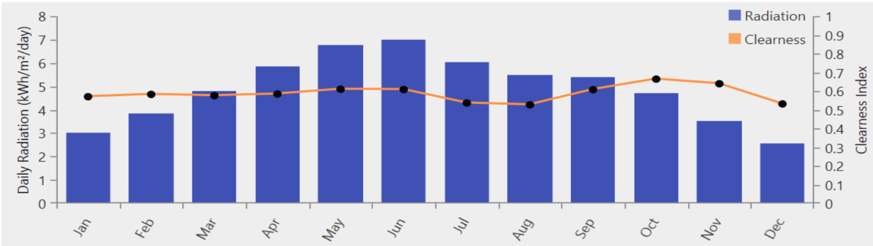
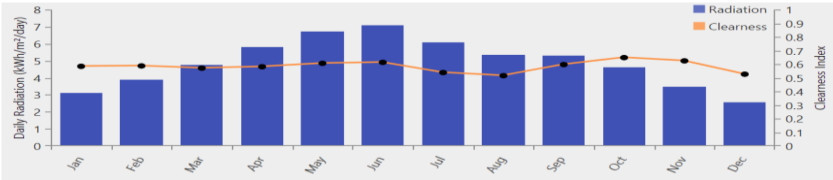


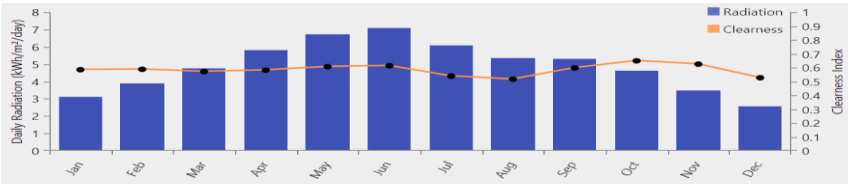
a) Plant-1



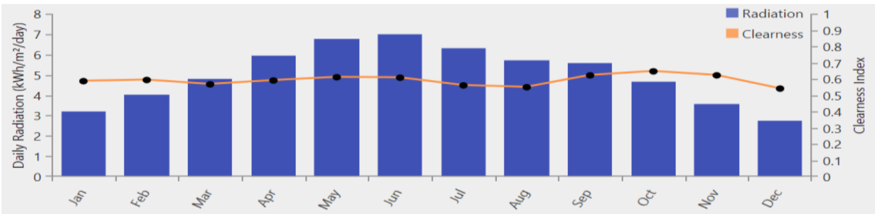
b) Plant-2



c) Plant-3



d) Plant-4



e) Plant-5

Figure 10. Annual daily radiation and clearness index

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

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

Using a reference ambient temperature of 20 C and global radiation of 800 W/m2, Tamb is the ambient temperature, GS is the location-specific global solar radiation, and NOCT is the normalized operating temperature of the cell.

2.6.2 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. It is a zinc-bromine battery with a 20-year expected life.

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.

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

The battery's state of charge at time t is denoted as SOC (t), while total load demand, net inverter efficiency, battery round-trip efficiency, total output power, and self-discharging rate are represented by $P_L(t)$, $\eta_{battery}$, and $P_{GA}(t)$.

The set of expressions that are near or equal to the total is where the ceil places the expression. The battery bank is used for storage in a hybrid system, but it also keeps the balance between power supply and demand. In connection to the time, the state of the charge, energy output, and consumption are all evaluated.

2.6.3 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. The converter only uses its rectifier mode when there is enough renewable energy to charge the battery storage system. The converter is rated as having a 95% efficiency. 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]:

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

where $P_{input}(t)$ denotes the converter's input power and conv the efficiency of the converter.

2.6.4 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] connects the output and rated power of a diesel generator.

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

where NDG is the total number of identical diesel generators, PDG is the sum of the generators' output power, and Diesel is the generator's efficiency.

The planned hybrid system's estimated CO2 emissions were calculated using the Equation (8) from [34]:

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

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 Heating Value of Fuel in MJ/L, Tons of Carbon Emitted per TJ, and the percentage of oxidized carbon, respectively. One last point to consider is that 1 gram of carbon is included in 3.667 grams of CO2.

2.6.5 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. In the anode area, hydrogen gas oxidizes, releasing electrons and producing ions as shown in Equation (9) from [40].

Anode Equation

$$2H_2 = 4H^+ + 4e^- \quad (9)$$

At the cathode, oxygen interacts not only with the electrons from the electrodes but also with the ions from the electrolyte and water.

Water is the waste product that is taken out of the cell in this instance. Oxygen joins H+ ions from the electrolyte and water, as well as electrons from the electrodes, at the cathode. At the cathode, oxygen interacts not only with the electrons from the electrodes but also with the ions from the electrolyte and water.

Water is the waste product that is taken out of the cell in this instance. Oxygen joins H+ ions from the electrolyte and water, as well as electrons from the electrodes, at the cathode Equation (10) shows the reaction [40].

$$O_2 + 4e^- + 4H^+ = 2H_2O \quad (10)$$

It has a fuel cell that is a "Generic Small Size Generator." It is connected to the system's 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 0.15 000 hours.

2.6.6 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]

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

2.6.7 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.

3 Results and Discussion

Using the NPC and LCOE values mentioned previously in this section, the simulation was run in the Homer Pro program to determine the most efficient system. 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.

3.1 *Sensitivity Analysis*

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 is crucial to investing because inflation can reduce the value of investment returns. Inflation affects all aspects of the economy, from consumer spending, business investment and employment rates to government programs, tax policies, and interest rates[44]. Inflation rate is higher in this year since December 2008 [45]. For a technical and financial study of the optimal hybrid system, Models are explained using 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. 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.

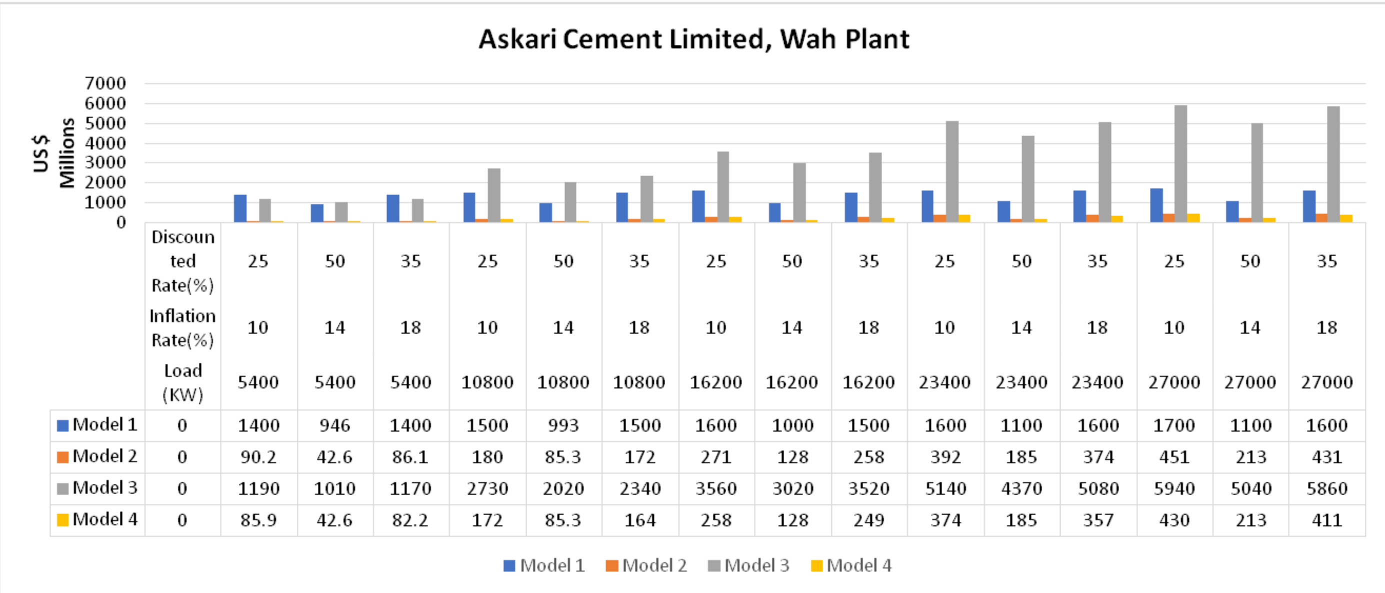
Model-2 and 4 NPC will be at least US$80.9 million by taking on 30% of Plant-2's load, with inflation and the discounted rate set at 50% and 14%, respectively. Model-2 and 4 NPC will be at least US$162 million by taking on 60% of Plant-2's load, with inflation and the discounted rate at 50% and 14%, 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 Model-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 Model-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 Model-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 Model-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 Model-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.



	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

(a)

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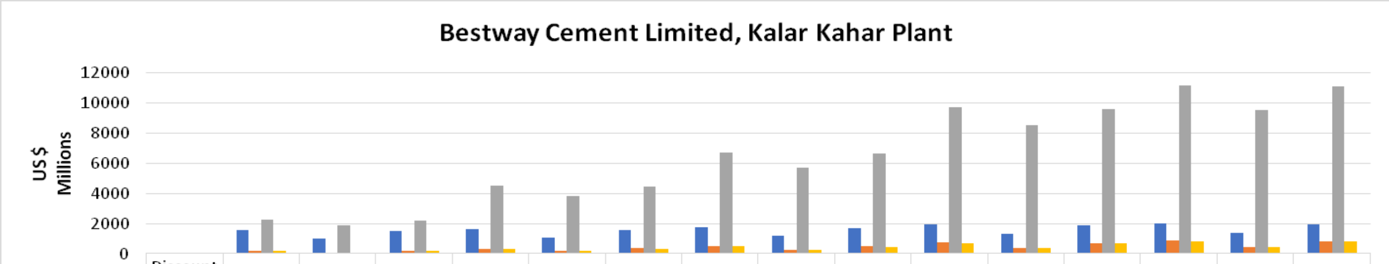
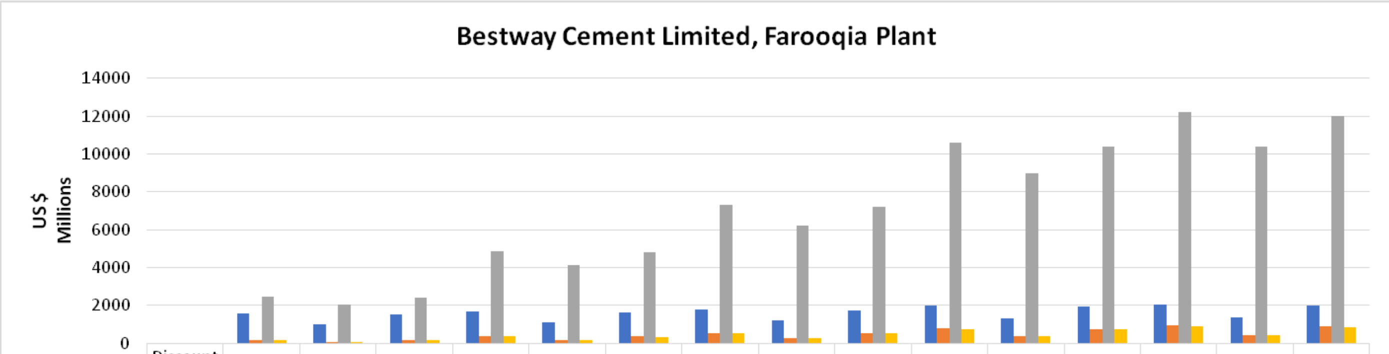


	Discounted Rate(%)	25	50	35	25	50	35	25	50	35	25	50	35	25	50	35
	Inflation Rate(%)	10	14	18	10	14	18	10	14	18	10	14	18	10	14	18
	Load (KW)	10200	10200	10200	20400	20400	20400	30600	30600	30600	44200	44200	44200	51000	51000	51000
Model 1	0	1540	988	1490	1660	1080	1600	1770	1170	1720	1930	1290	1870	2010	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)



	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)

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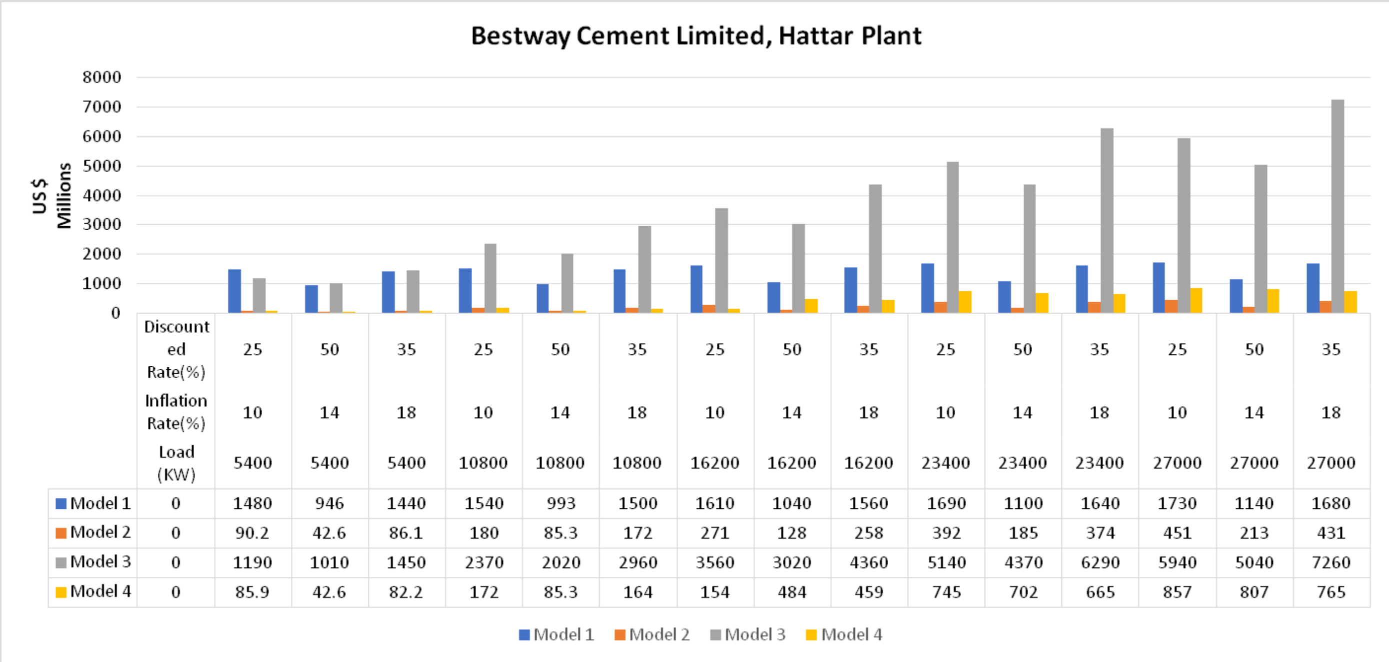
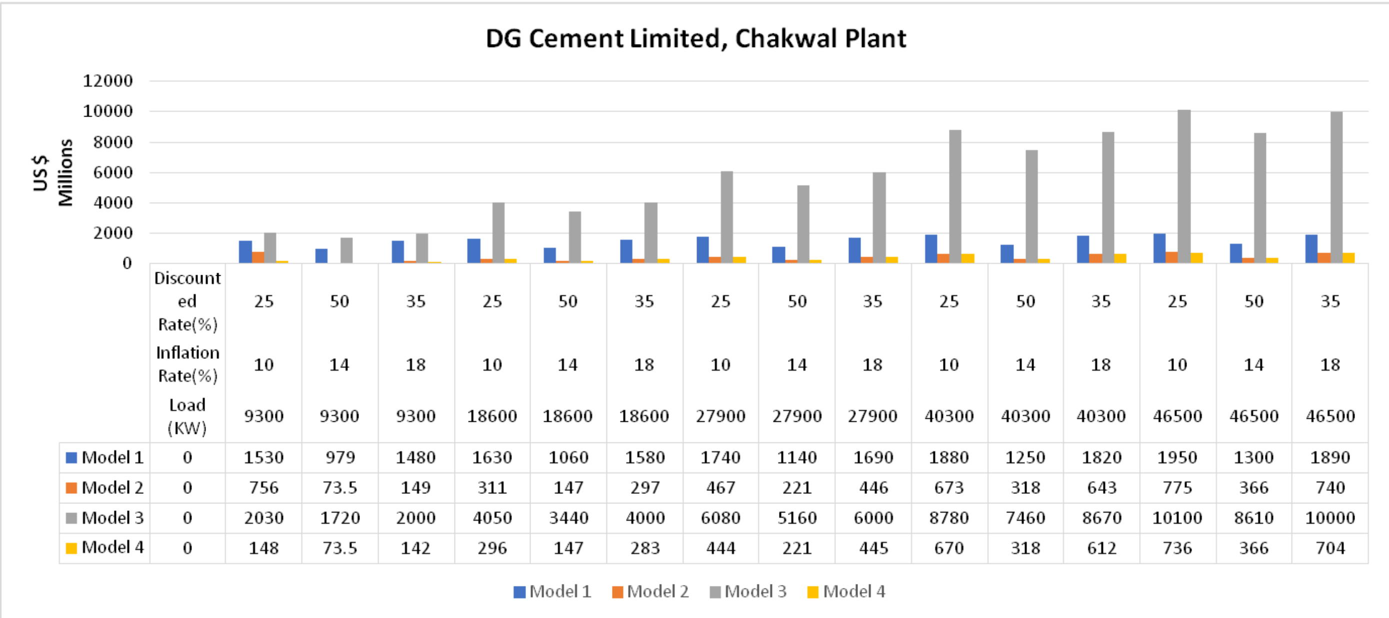


(d)



(e)

Figure 11. Sensitivity analysis for Plants (**a**) 1, (**b**) 2, (**c**) 3, (**d**) 4, and (**e**) 5

3.2 Cost Analysis

The initial cost, operating cost, LCOE, and NPC of all plant model costs are displayed in Table 3-7. NPC for Plant-1 from Models-1 and 2 is US$2630M and US$575M, but Models-3 and Model-4 have corresponding 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.

Figure 12 shows that the NPC for Plant-5 is $2830 million for model 1, $1,87 million for Model-2, $8,480 million for Model-3, and $923 million for Model-4.

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Table 3. Models-1, 2, 3, and 4. Comparison of Plant-1's NPC, initial cost, COE, and O&M

Cost type	Model-1	Model-2	Model-3	Model-4
NPC	US$2630 M	US$575M	US$4970M	US$540M
Initial cost	US$634M	US$14.8M	US$3060M	US$95.8M
COE/kWh	US$1.22	US$0.266	US$2.30	US$0.249
Operation and maintenance	US$146M /yr	US$40.8M/yr	US$4,805M /yr	US$32.4M/yr

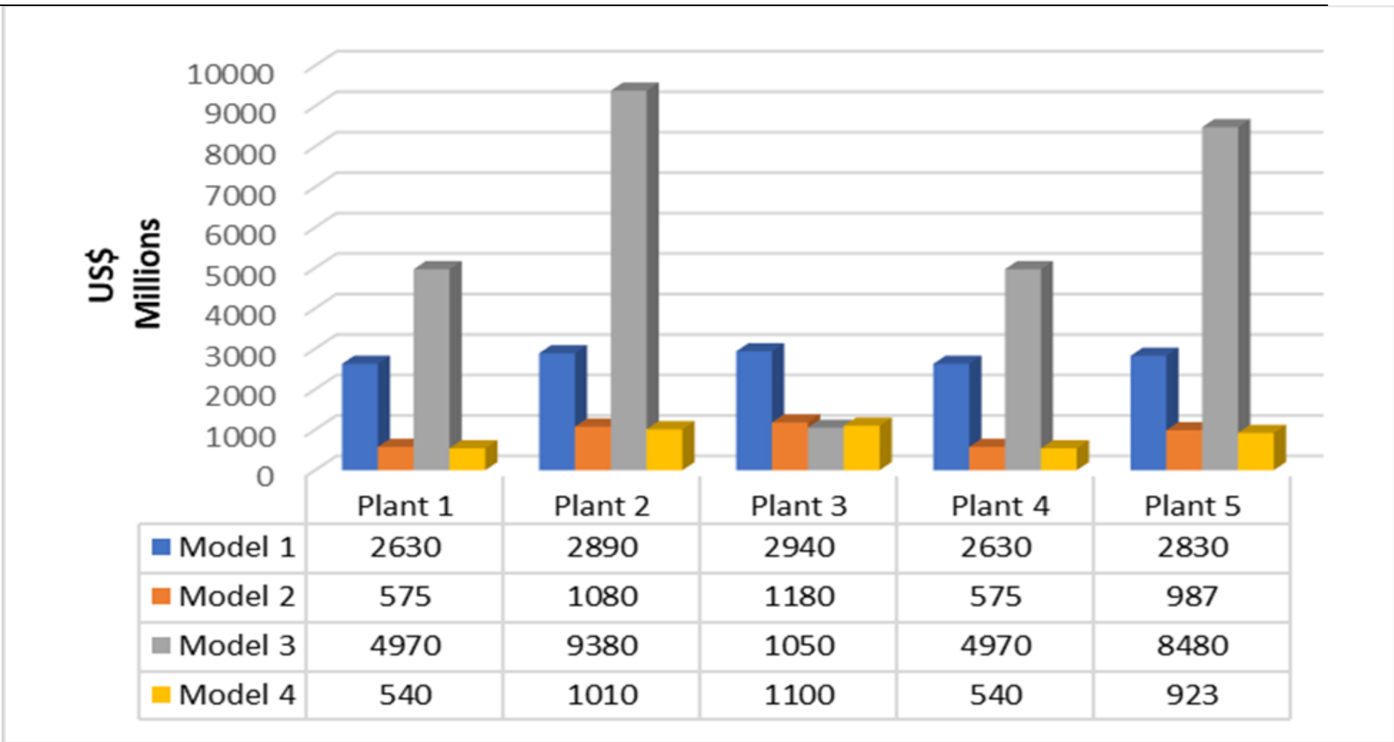


Figure 12. Comparison of the net present costs for Plants 1, 2, 3, 4, and 5

Table 4. Models-1, 2, 3, and 4. Comparison of Plant-2's NPC, initial cost, COE, and O&M

Cost type	Model-1	Model-2	Model-3	Model-4
NPC	US$2890 M	US$1080M	US$9380M	US$1010M
Initial cost	US$743M	US$27.6M	US$5780M	US$175M
COE/kWh	US$0.706	US$0.265	US$2.30	US$0.248
Operation and maintenance	US$156M /yr	US$76.8M/yr	US$263M/ yr	US$61.1M/yr

Table 5. Models-1, 2, 3, and 4. Comparison of Plant-3's NPC, initial cost, COE, and O&M

Cost type	Model-1	Model-2	Model-3	Model-4
NPC	US$2940 M	US$1180M	US$1050M	US$1100M
Initial cost	US$764M	US$30M	US$6280M	US$190M
COE/kWh	US$0.660	US$0.264	US$2.20	US$0.248
Operation and maintenance	US$158M /yr	US$83.5M/yr	US$287M/ yr	US$66.6M/yr

Table 6. Models-1, 2, 3, and 4. Comparison of Plant-4's NPC, initial cost, COE, and O&M

Cost type	Model-1	Model-2	Model-3	Model-4
NPC	US$2630 M	US$575M	US$4970M	US$540M
Initial cost	US$634M	US$14.8M	US$3060M	US$94.5M
COE/kWh	US$1.22	US$0.266	US$2.30	US$0.249
Operation and maintenance	US$146M /yr	US$40.8M/yr	US$139M/y r	US$32.5M/yr

Table 7. Models-1, 2, 3, and 4. Comparison of Plant-5's NPC, initial cost, COE, and O&M

Cost type	Model-1	Model-2	Model-3	Model-4
NPC	US$2830 M	US$987M	US$8480M	US$923M
Initial cost	US$720M	US$25.2M	US$5230M	US$159M
COE/kWh	US$0.760	US$0.265	US$2.28	US$0.248
Operation and maintenance	US$154M /yr	US$70M/yr	US$236M/y r	US$55.6M/yr

3.2.1 Winning case or lowest Cost System

The lowest cost system, also known as the winning system, is the ideal system with the lowest net present value. The lowest cost system may also be altered by adjusting the sensitivity settings and choosing the system from the simulated results.

3.2.2 Base Case

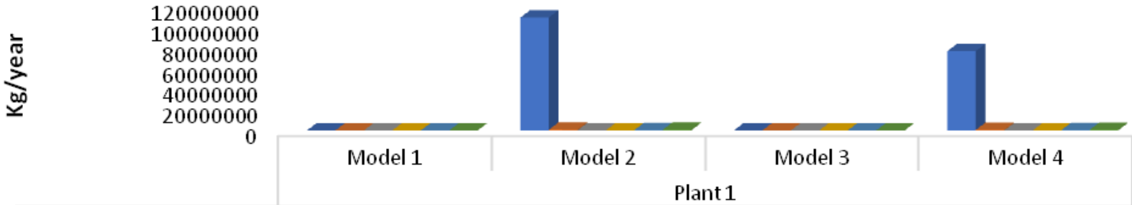
Because it has the lowest capital cost of all the systems mentioned, the basic case architecture in the models offered is the one that was selected. Depending on the situation, the model's winning or lowest-cost system may also be the base system. Going to the summary option and choosing the base case from all the optimized systems by your preferences will also allow you to change the base case system.

The simplest example and least expensive system are just used to highlight how the Present NPC and the systems differ from one another. In this research, Model-2 serves as the Base Case.

3.3 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. According to data from the US Energy Information Administration, 1 kWh of power produced 632.00 g of CO2 emissions. In addition, every kWh results in the production of 1.34 g of nitrogen oxides and 2.74 g of carbon dioxide. Harmful gases including nitrogen oxides (NO), sulfur dioxide (SO2), carbon monoxide (CO), unburned hydrocarbons (UHCs), or carbon dioxide are not present in the renewable hybrid Model-1 or Model-3 (CO2).

The ecology won't be harmed by the dangerous gases used in this sustainable hybrid model. The generator in the hybrid Model-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 13–17.



	Model 1	Model 2	Model 3	Model 4
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 13. Comparisons of models with respect to GHG emissions for plant-1

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	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

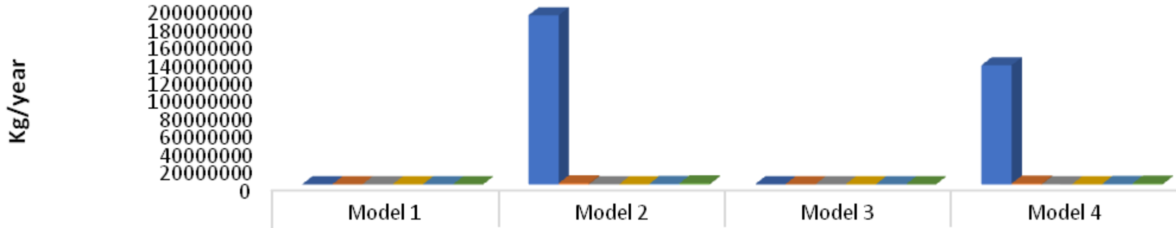
Figure 14. Comparisons of models with respect to GHG emissions for plant-2

	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 15. Comparisons of models with respect to GHG emissions for plant-3

	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 16. Comparisons of models with respect to GHG emissions for plant-4



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 17. Comparisons of models with respect to GHG emissions for plant-5.

4. Conclusions

Diesel generators continue to dominate the market for electrical generators in off-grid isolated locations, which has increased GHG emissions. The utilization of renewable energy technologies in off-grid hybrid energy systems 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 NPC, 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 0% GHG emissions.

- Models 2 is the best in terms of initial costs.

The most optimal COE and 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 CO2 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 % CO2 Emissions.

- For Bestway Cement Limited, Farooqia, Model-4 with NPC and COE of US$1100M and US$0.248/kWh is the most useful model. The Model-4's yearly operating expenses are US$66.6 million with a decrease in CO2 emissions of 29.97%.

- The most useful model is Model-4 for Bestway Cement Limited, Hattar, with NPC and COE of US$540M and US$0.249/kWh. The Model-4 has annual operating expenses of US$32.5 million and CO2 emissions reductions of 29.56 %.

- The most feasible choice for DG Cement Limited, Chakwal, is Model-4 with NPC and COE of US$923M and US$0.248/kWh. The Model-4 has annual operating expenses of $55.6M and CO2 emissions reductions of 29.56 %.

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Abbreviation

GHG	Greenhouse Gases
COE	cost of energy
CO_2	carbon dioxide
CRF	capital recovery factor
HES	hybrid energy system
HMS	hybrid micropower system
HOMER	Hybrid Optimization of Multiple Energy Resources
LF	load following
NASA	National Aeronautics and Space Administration
NOx	nitrogen oxide
NPC	net present cost
O and M	operation and Maintenance
PV	photovoltaic
RES	renewable energy source
SO_2	sulfur dioxide
Cann, the total	total yearly cost
Pin	input power of converter
PL	load demand
Pout	output power of converter
RS	amount of solar radiation striking the PV array
TC	PV cell temperature

Tp project lifetime

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