B.Sc. in Electrical and Electronic Engineering Thesis

Towards sustainable energy technologies at COVID-19 hospital: A groundbreaking path to healthcare system

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CANDIDATES' DECLARATION

This is to certify that the work presented in this thesis, titled, "Towards sustainable energy technologies at COVID-19 hospital: A groundbreaking path to healthcare system", is the outcome of the investigation and research carried out by us under the supervision of Muhammad.

It is also declared that neither this thesis nor any part thereof has been submitted anywhere else for the award of any degree, diploma or other qualifications.

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CERTIFICATION

This thesis titled, **"Towards sustainable energy technologies at COVID-19 hospital: A groundbreaking path to healthcare system"**, submitted by the group as mentioned below has been accepted as satisfactory in partial fulfillment of the requirements for the degree B.Sc. in Electrical and Electronic Engineering in February 2021.

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Lastly, this research would not have been completed without the support and motivation from our beloved family, friends, teachers, classmates who has been with me through thick and thin during this marvelous adventure in completing our bachelor degree. Above all, to the Great Almighty, Allah S.W.T., the author of knowledge and wisdom, for his countless blessings.

Dhaka
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ABSTRACT

The current energy demands in Bangladesh far supersedes the supply. The thesis provides an efficient way to account for the energy deficit by using a renewable hybrid model design. Solar, Wind and Biogas were the focus of this thesis for their abundance in the region of study. Our thesis explored the possibilities of implementing a hybrid energy system in a makeshift COVID-19 hospital in Purbachal, Bangladesh. The hybrid model developed using HOMER software utilized solar, Wind and Biogas in a configuration which achieved the best COE and NPC values. The model adjusted parameters such as fuel cost, wind speed, solar radiation, electricity price and component cost for smooth and realistic simulation. From our simulations, we observed that for the region of study, the wind energy was not a feasible option and without Biogas, the PV-Wind or only PV system had a COE of 0.492 and 0.516 USD respectively. We find good optimize result for **PV-Bio as generator-Battery** system.Where we are getting the COE around 0.176 USD with a considerable amount of initial capital which is 82806.25 USD . Even though the model was primarily fashioned for the healthcare sector in Purbachal, Bangladesh. The model can easily be modified for use in any region of the world and be re-purposed for use in other industries.

Chapter 1

Introduction

In Bangladesh, though, the COVID-19 restrictions and the general alertness has dwindled significantly along with time. The country must remain vigilant for possible upcoming spikes in infection rates. Most researches predict an up tic in infection rates in the coming winters. Thus, the general populous as well as the country as a whole must seek to implement more permanent measures to counteract the possible up tic and curb the rise of COVID-19 infection. In December 2019, Coronavirus was first detected in Wuhan , China, [1]. A Public Health Emergency of International Concern (PHEIC) was declared in January 2020 and a pandemic in March 2020 following the outbreak. Upwards of 40.8 million cases were reported as of 21 October 2020, with more than 1.12 million deaths being attributed to COVID-19. [2]. The spread of COVID-19 increases with the increase in concentration of individuals in a specific area. Coronavirus spreads effectively through the air, when an infected individual breathes, choughs, sneezes, sings or speaks usually in the form of droplets or aerosols. [3]. As countries like Bangladesh already boasts a high population density, the risk of coronavirus are greatly accentuated. On 16 March, the Government closed all educational institutes (schools, colleges and Universities) as a means to contain the COVID-19 outbreak. [4] On 8 March 2020, the country's epidemiology institute, IEDCRR, announced the first three identified cases. Since then, the pandemic has gradually enshrouded the whole nation with an ever increasing infection rate. Finally, on 18 March 2020, the Government of Bangladesh ordained the National Preparedness and Response Plan (NPRP). for COVID-19 with a budget of USD 29,550,000 million. [4]. In early November total number of cases found in Bangladesh is 417,475 Deaths:6,036 Recovered: 335,027 [5].As of 18 March, following the government directive, public hospitals, such as Shaheed Suhrawardy Medical College (SSMC) Hospital, Dhaka Medical College (DMC) Hospital, Chittagong 250-Bed General Hospital, Chittagong Medical College Hospital, and most Sadar District hospitals of the country as a precautionary measure for the isolated care of suspected COVID-19 patients, the establishment of specific isolation wards [4]. As of April 18 the situation is as follows: COVID-19 infections have already been reported in 53 of the 64 districts;

6059 isolation beds have been made available along with 595 doctors, 546 nurses, 130 medical technologists and 350 other healthcare staff with necessary experience and skills, to treat COVID-19 patients (IEDCR, 2020). With limited resources, expanding the healthcare capacity proves to be a challenge for Bangladesh. In 1980, there were only 28 ICU beds in Dhaka city. Since then the number of ICU beds has gradually increased [6].The total number of beds in hospitals was 1,27,360 in 2017-18. Of these, there were 48,934 in public hospitals and 78426 in private hospitals [6]. Currently, Bangladesh's total medical capacity is 141,903 hospital beds or 0.84 beds per 1000 people, according to ('The Daily DhakaTribune', March 21, 2020) [7].

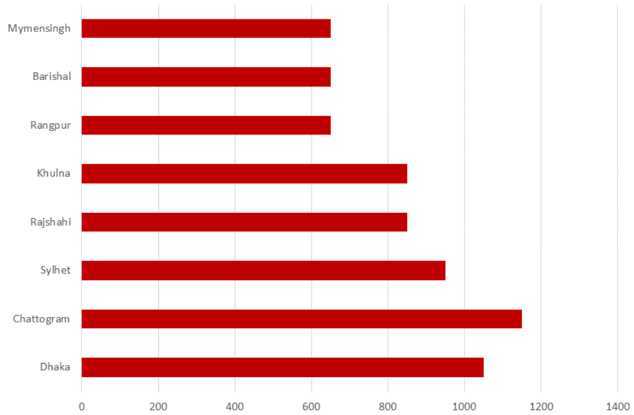

Figure 1.1: Division wise number of isolation beds
[7]

Figure 1 shows the distribution of isolation beds with respect to Division. The largest number of isolation beds are available in the divisions of Dhaka and Chattogram. Chattogram Division has 1101-1200 beds while Dhaka Division has 1001-1100 beds. Following these two divisions, the Sylhet Division's third-highest potential is 901-1000 beds, while the divisions of Rajshahi and Khulna have 801-900 beds. The divisions of Barishal, Mymensingh, and Rangpur have the smallest number of isolation beds [7]. On April 9, a plan to set up a 2,000-bed Isolation Centre at the ICCB was put forward by the Health Minister. On the other hand, 1,300 beds at the DNCC Market and 1,200 at Uttara Diabari were ready to serve. Subject to these, 601 other district institutions and Upazilas, including the capital, were restored as coronavirus isolation centers [8]. Health Minister Zahid Maleque inaugurated a 2,000-bed hospital at International Convention City Bashundhara on May 17, 2020.(thedailystar,May 17, 2020) So, sustaining the uptake in medical institutions proves to be a great challenge for Bangladesh as it needs to provide electricity in such greater number. Here, the use of renewable energy might be an effective solution meet the increased demand. As of January 2017, the country's total installed electricity generation capacity (including captive power) was 15,351 megawatts (MW) [9] and 20,000 megawatts in 2018 [10]. In 2015, 92 percent of the urban population and 67 percent of the rural population and a national average of 77.9 percent of the population had access to electricity in Bangladesh [11].Bangladesh will need an estimated 34,000 MW of power by 2030 to sustain it's economic growth of over the 7 percent mark. [12] In Bangladesh, power sectors that highly dependent on conventional fossil fuel including gas and coal. Thus, over time, we have to find alternative solutions to meet our energy demands. Bangladesh has a high potential for renewable energy, this significantly increases the number projects required to meet the electrical energy demands throughout the country. The most prevalent form of renewable energy currently in Bangladesh is PV based off grid system including SHS, nano-grid, and mini-grid, where biomass also have high potential to integrated significantly to the existing energy infrastructure. Our target here is to design renewable ICCB Covid medical facilities which satisfied sustainability. The COVID-19 outbreak has brought forward the ingrained vulnerabilities of health systems across the world. A lack of reliable power in healthcare facilities has eroded the standard of healthcare for millions of people, in particular in Sub-Saharan Africa, South Asia and South-East Asia, long before the pandemic made regular headlines around the world. [13]

Figure 1.2: Renewable energy access in healthcare in Rural Sub-Saharan Africa [14]

Sustainable energy access study for healthcare facilities in the global South has been carried out [15].Where the stated about the projects and possibilities of renewable energies in healthcare facilities in countries like Zambia,Tanzania,Rwanda,Haiti. End use energy analysis has done in Malaysian Public Hospital [16]. And it was estimated that the highest amount of energy can be saved for 60 percent speed reduction using a variable speed driver . A analysis of energy supply trends in 11 sub-Saharan African countries using national surveys and representative samples from more than 4,000 public and private health facilities found that as a primary or backup source, hundreds of clinics and hospitals use solar photovoltaic (PV) on-site energy generation. [17] Lanre, Richard, Saad, Daniel showed that the PV / wind/diesel/battery hybrid system configuration is considered optimal for rural health centers in Iseyin, Sokoto, Maiduguri, Jos Enugu regions. In contrast, hybrid systems involving PV / diesel/battery are deemed suitable for Port-Harcourt considering renewable energies' efficiency [18].

The considerations of this paper is focused on Renewable energy sources (RESs) such as photovoltic(PV) ,wind turbine (WT), bio-gas, biomass and spans over the integration of energy storage systems (ESSs) like batteries to the hybrid design increasing the reliability of the system to a higher standard. Our system has been designed using hybrid optimization model for electric renewable (HOMER) . The most commonly used applications for hybrid systems designing such systems worldwide are HOMER, RET Screen, and IHOGA. NREL (National Renewable Energy Laboratory, USA) has developed a hybrid optimization model for electric renewables (HOMER) and model hybrid systems in more than 192 countries [19].

The Renewable energy sources (RESs) considered in this paper are photovoltic(PV) , wind turbine (WT) , bio-gas, biomass , moreover the integration of energy storage systems (ESSs) like batteries to the hybrid design increases the reliability of the system to a higher level.We have designed our system using hybrid optimization model for electric renewable (HOMER) .

Asif Khan and Nadeem Javaid from Pakistan used HOMER for energy management system for hybrid PV-WT-FC-DG system [20].Joan D Rozario and Shahinur Rehman from Bangladesh used HOMER's bio-gas tool with solar energy software to improve system efficiency and provide a cost-effective approach [21]. Soumya, Hosna ,Sarker from RUET designed Solar-PV/Biogas/Diesel Generator Hybrid Energy System for rural area locallaly name as "CHAR" in Rajshahi. [22] They found the best configuration at COE and NPC of USD 0.18 and USD 118007.39 [1] respectively. Kamran, Bilal, Mudassar from pakistan PV/Wind/diesel/battery Hybrid system for Energy Centre of UET Lahore [23] They have done techno economical analysis using HOMER Pro. Muhammad Umer Khan, Muhammad Hassan, M. Muhammad Hassan, M. M. Haseeb Nawaz for Southern Punjab Remote Area Electrification (Multan) [20] . They did the PV/Wind/Biomass/Biogas Hybrid System techno-economical research.Their hybrid system scheme is further categorized as a biomass resource in two groups, one using animal manure and the other using crop residue.

1.1 Contribution

In this paper , we presented the renewable energy framework on the Healthcare Archives of Bangladesh. To the best of our perception, This study is the ***first*** to model a COVID-19 hospital On the outskirts of Dhaka city, Purbachal, with hybrid device facilities. This may be called a sub-urban environment with a number of open spaces. The fundamental objective of this work is to find the possibilities of sustainable energy access on this platform. As we know COVID-19 is a emergency situation but designing a hybrid system could supply the energy even when this situation will over. Because this hospital area was used for many events as well[Figure1.3]. So this is not just a temporary solution.

[1]Some of the amounts reported were in BDT that were further converted to USD

Figure 1.3: A denim expo in ICCB

Our work encompasses : (i) The necessary load demands for a COVID-19 hospital (ii) Access of different renewable sources of the hybrid system. and (iii) Analysing the solutions of various hybrid configuration. The remaining part of this paper is outlined as follows: In the Section 2.4 we discussed about different resources like Solar energy ,Bio-gas energy and Wind energy In Section 4.2 we have briefly talked about the HOMER input datas for our design. Section 5 and Section 6 reports the results of our proposed model, followed by conclusions in Section 7.

Chapter 2

Preliminaries

Here in our country, with a per capita availability of 279 KW-hr per year, only 59.60 percent of the population has access to electricity. [24]. Bangladesh has more than 87,319 villages and most of them are not connected to the power network. [25]. Bangladesh's power generation faces some obstacles, such as a shortage of natural gas, inefficient old power plants, rising population numbers, etc. It largely depends, almost 63 percent, on natural gas. [26]. There are some issues created by this unhealthy dependency. Electricity production would be disrupted due to declines in natural gas generation or shortages in the supply of natural gas. 23 percent of the electricity is generated from power plants over 20 years old. [24]. So the using of Renwable energy sources (RESs) is a crying need for our country.

2.1 Introduction

Previously renewable energy sources (green energy) were viewed as technologically impracticable or not economically feasible. Nonetheless, the cost of renewable energy investment is such a As biogas plants are typically higher compared to fossil fuels, but considered over time, when all externalities (environmental costs, health risks, job creation, etc.) and lower operating costs are taken into account, the use of renewable energy becomes economically viable [27]. Therefore, Renewable energy is now a topic of urgent and increasing importance in renewable energy and agricultural development, as well as encouraging good governance, power utilities and private entrepreneurs to assess technology more carefully with practical life.

2.1.1 Defination of Energy

The capacity to do work is the scientific concept of energy. It can also be characterized as power that can be transformed into motion or that can lead to resistance being overcome. Kinetics and

Table 2.1: Some projects in Bangladesh

Project name	Organization
Renewable energy development project-	REB/IDCON
Sustainable rural energy	LGED
Solar & Wind resource assessment project	RERC, DU
SHS project	Grameen Sakti
PREGA	REB/BPDB
GTZ funded project	REB
Biogas pilot project	LGED
SHS project	BRAC
CHT SHS project	BPDB
RET feasibility study	BCSIR
SHS project	TMSS
Solar home lighting system	Centre for mass education in science (CMES)
Solar home system	Integrated Development Foundation (IDF)
Wind power generation	BPDB
Hybrid system	Grameen Sakti, BRAC
Wind mill water pumping	LGED
Micro hydro power plant	LGED
Biogas plants	BCSIR, BRAC

potential are the two main sources of energy.

2.2 Perspective of Renewable Energy Sources(RESs) in Bangladesh

For the period 2010-2021, the Perspective Plan of the Planning Commission of the Government of Bangladesh has proposed an energy mix to achieve 20,000 MW of generation by 2021. The electricity generation targets for 2013 and 2015 are 7,000 MW and 8000 MW, respectively. [28] Although there are many challenges, Bangladesh is steadily rising in the field of RESs.Some government departments and NGOs are working on it. Table 2.1 is giving us some ideas of completed and ongoing project all over the country by different organization.

2.3 Energy demand assessment of ICCB Covid hospital

A crucial step in the planning and design process of energy participation in the estimation of energy demand. It provides information on the various electrical equipment types, their power levels, and the time of operation during the day.

In table 1, we have given the data of various equipment and calculated the total energy, which is 313.9 units per day. However, the peak load is 44.19 kW/day. The proposed Covid Hospital's

Figure 2.1: Bashundhara International Convention Centre’s 2,000-bed isolation facility for Covid-19 patients (ICCB)

[29]

monthly load profile is shown in Fig. 5. In HOMER, we can select the load profile based on residential, community, industry, etc., and also, we can choose the peak months based on a country’s geometrical position.

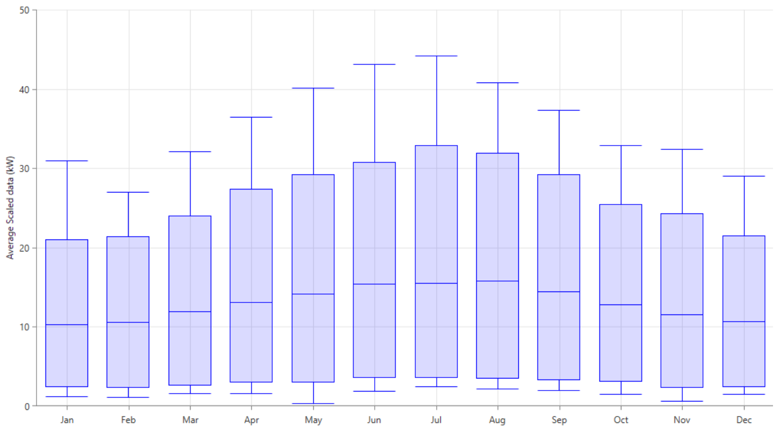

Figure 2.2: Seasonal profile of load

2.4 Resource potential assessment

Bangladesh is endowed with the profound significance of renewable resources, such as sunlight, wind, biomass, etc. In the previous, we were mostly dependent on non-renewable resources such as gas, oil, coal, etc., as shown in Table 2, which expresses Bangladesh’s energy scenario. Therefore we need to progressively reduce non-renewable sources because of their environmental damage and rising rates.

Table 2.2: ICCB Covid-19 Hospital's load overview and expected demand

Load Description	Quantity	Rated Power (W)	Total Power (W)	Daytime hour (h/d)	Night hours (h/d)	Total ontime (h/d)	Total Energy (kWh/d)
Lighting- CFL (indoor)	350	15	5250	2	6	8	42
Lighting-CFL (outdoor)	20	40	800		12	12	9.6
Fan (Ceiling/wall)	50	60	3000	6	6	12	36
Blood bank refrigerator	5	70	350	12	6	18	6.3
Vaccine refrigerator	20	60	1200	12	6	18	21.6
Small refrigerator	20	300	6000	5	5	10	60
Patient Ventilator	75	200	5400	10	-	10	54
Nasal Cannula	50	90	4500	10	-	10	45
Lab Autoclave (40-60L)	5	3000	15000	1	-	1	15
Blood Gas analyzer	20	50	1000	0.5	-	0.5	0.5
Electrocardiograph	20	80	1600	0.5	-	0.5	0.8
Suction Pump	20	24	480	10	-	10	4.8
Desktop Computer	10	150	1500	5	-	5	7.5
TV set	10	80	800	4	2	6	4.8
Mobile charger	50	20	1000	2	4	6	6
Total			47880			127	313.9

Energy sources	Target period		
	2010	2021	2030
Gas	88%	30%	28%
Oil	6%	3%	5%
Coal	3.70%	53%	38%
Hydro	2.70%	1%	4%
Nuclear	0%	10%	19%
Renewable	0%	3%	6%

Table 2.3: Energy perspective in Bangladesh

2.4.1 Solar energy resources potential

In Bangladesh technologies based on solar are a very promising alternative to generators because the sun is abundant of the energy source , For operating the equipment of a healthcare facility, in order to convert the DC power input to alternating current (AC) power, photovoltaic systems must be fitted with inverters. Advance medical equipment technology, allows devices to make use of the DC power supplied directly by Pv modules. ICCB located at north Dhaka , has longitude and latitude of 23° 49.6'N and 90° 25.6'E respectively.

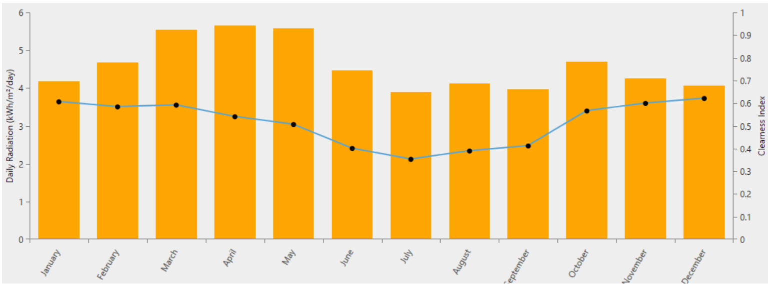

Figure 2.3: Solar irradiance for our project location

Figure 4 shows that the annual scaled solar activity average is 4.59 kWh/m2/day over ICCB.

2.4.2 Producing biogas by animal manure

The biogas engine transforms mechanical energy into biogas energy. The engine of biogas is coupled with an alternator driven by mechanical energy for the generation of electricity. Bangladesh is known as an agricultural nation rich in biogas resources. There are many dairy farms near the place we have selected for your design as well as many families have 3-4 cows in the purbachal express highway area. As this location situated at the corner of the city this place still a sub-urban area with lots of open spaces. There are several large agro-farms to meet the city's daily demand for milk and meat. For example North Bengal dairy (Vatara), Dairysun(Bashundhara),Meghdubi agro etc. We can easily obtain the available biogas resourses for our design by applying good management. Therefore, bio-gas from animal waste may be an excellent source.

One cow produces 15–16 kg of cow manure per day; 100 cows = 100 x 15 = 1500 kg per day [30] Total fuel produced per day by bio-gas = 1.65 tonnes. 0.036m3 of bio-gas is derived from one cow's manure. [21] In a report, the bio-gas needed for electricity generation of 1kw is 0.7m3 / h. [31] [32]

The biogas plant economy is characterized by large investment costs, a few operational and maintenance costs, mostly free raw materials (animal dung, poultry litter, aquatic weeds, agricultural waste, terrestrial plants, sewage sludge, etc.) and eventually income from gas formation.Other external values will be added: processing bio-fertilizers, reducing CO2 emissions, reducing health costs and reducing cooking time and biogas fuel collection. The installation cost of a typical biogas plant is location specific (it depends on the cost of installation of a typical biogas plant, area topography, labor costs at the site location, involvement in the community, learning curve and use of the biogas product).The economic performance of a biogas system is also likely to be site-specific, as it depends on the existing market price of inputs and production, the practices of natural agriculture and the organizational system adopted by the group concerned. [33].

Figure 2.4: Dairy farms can be a source for bio-gas

Figure 2.5: Different agro farms near ICCB [34]

2.4.3 Wind energy resources potential

The wind is an energy source that is renewable and, depending on the geographical position, it can be divided according to its ability into a variety of categories. The latitude of Bangladesh is between 20.30 - 26.38 degrees north and 88.04 - 92.44 degrees east [35]. Analysis of upper air data by the Center for Wind Energy Technology (CWET) India shows that Bangladesh's wind energy resource for electricity production is not sufficiently strong (¡ 7 m/s) for grid-connected wind parks in most of the country. This sector is under research mainly at coastal zone [36]. Mini and small wind turbines ranging from 1 to 100 kW are primarily used for rural -grid electrification and can be generally used in households and small populations.Medium and large wind turbines with a power ranging from 100 kW to several megawatts can be used for both on-grid (through main grid connection) and off-grid electrification. Data on wind resources is collected by NREL (National Renewable Energy Laboratory) tools available in Database with HOMER Pro. The data shown in Fig. 5 implies that the annual average wind speed of the ICCB is 4.42 m/s.

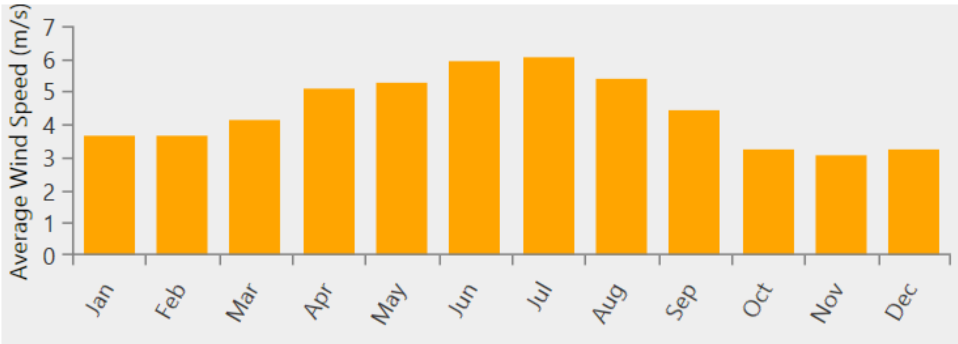

Figure 2.6: Average wind speed for ICCB

Chapter 3

System Model

In this chapter we described our model. In section 3.1 we explained our model.

3.1 Model Description

We need to develop the basic system model in any form of hybrid system design, first taking into account the available resources of that desired area. We will go on integrating applications after that. The input power diagram is presented in the Fig. 3.1. In this paper, DC buses and AC buses are used. The bus from DC combines the battery and PV panel output as displayed in Fig. 3.1. The AC bus mixes the output / input of the Biogas generator, AC load from the wind turbine and hospital. To perform, the invertion from DC to AC we used the inverters. On the next chapter we will show the implementation of this hybrid design into our software.

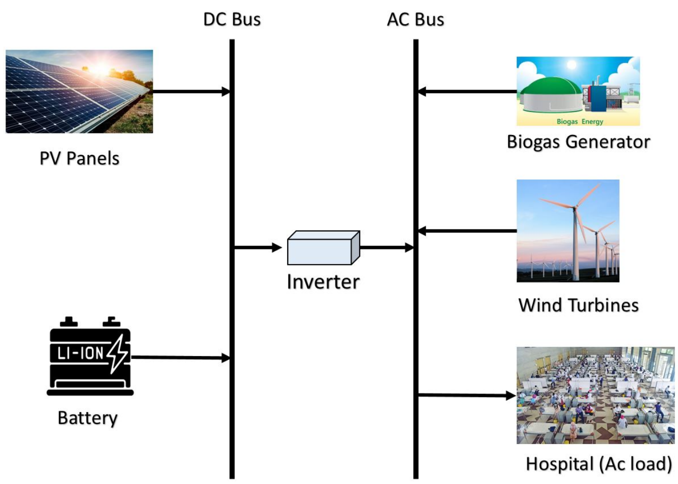

Figure 3.1: System model of hybrid system

Chapter 4

System optimization in HOMER

The software implementation of the hybrid design is shown in figure 4.1 . This schematic is diagram is based on the system model design shown in figure 3.1 .Now we will discuss about the software we have used and the input datas on the later segment.

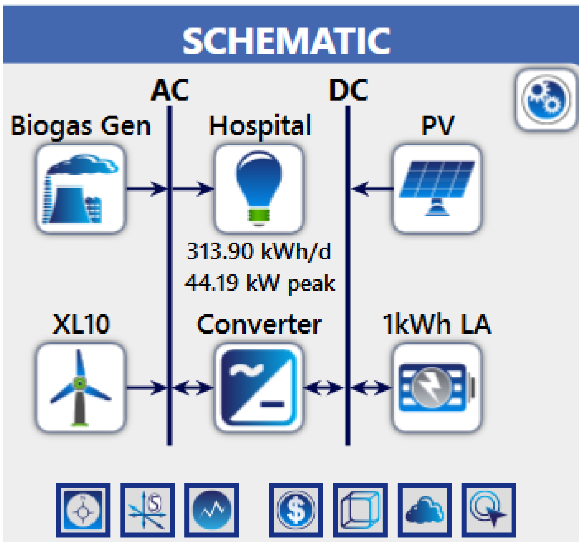

Figure 4.1: Schematic diagram of hybrid system in HOMER

4.1 Introduction to HOMER

HOMER Energy's HOMER Pro® microgrid program is the worldwide standard for microgrid design optimization in all industries, from village power and island utilities to grid-connected campuses and military bases.HOMER (Hybrid Optimization Model for Multiple Energy Resources), originally developed at the National Renewable Energy Laboratory and improved and distributed by HOMER Energy, nests three powerful tools in one software product so that engineering and economics work side by side. The HOMER Energy principles have been working with economic and engineering optimization of microgrids for over 25 years. Our collective vision is to empower people worldwide with tools, services, and information to accelerate the adoption of renewable and distributed energy sources.

HOMER Energy provides additional resources and the HOMER app, such as web-based and in-person training and HOMER usage assistance. We also configure the program for novel issues or equipment styles. Also, we provide a variety of advisory services related to renewable and distributed power strategies, economies, and technologies.

4.2 Hybrid system component data

4.2.1 PV Modules

Bangladesh's per-unit cost of generating solar energy started at seventeen to nineteen, which was later reduced to 10 cents over three years. [37].In this research, stan- dardized 1 kW capacity at plate PV modules are used. In local manufacturing, investment cost for 1 kW in Bangladesh range from BDT 80000-1000000 [38].So we took 1000 dollar/kw as cost. While the cost of replacement is 800 dollars / kw. And it's life span is 25 years.

4.2.2 Wind turbine

In 2018, it was conGrmed that around 5 million USD was spent by the Power Development Board (PDB) on a 2-megawatt wind power project for which USD 0.19 is the cost of production per unit. From the experts' perspective The Netherlands' wind turbines are the

nest. A turbine of one megawatt costs around 0.94-1 million USD. The price of the entire project, together with other costs, should not exceed 1.18 million USD [37]. Because of its low cutting speed, i.e. 2.5 m / s (5 mph), we have selected Bergey Excel 10 here. The BWC Excel 10 is a modern 10 kW wind turbine with a diameter of 7 meters (23 ft). it is designed for low maintenance, reliability, and automatic service in extreme weather conditions [39]. Production and replacement costs are USD 380,USD 235 respectively. The power of the wind turbine is 10 kW with 20 years of lifespan.

4.2.3 Bio-gas generator

Here in our country, the digester size is expected to be 70 m3 to generate 100 kWh of electricity everyday [40]. Generic bio-gas generators whose power can be set automatically are used in our research. With a lifetime of 15,000 hours, the generator has a 25 percent minimum load ratio. In our research, 1.65 tonnes / day of scaled annual average bio-gas fuel is taken. This can be done by 100 cow manure that is already mentioned in section 2.2.2 In Bangladesh, digesters cost is around USD 538 for 3.2m3 [40]. USD 1156 was taken as capital expense in another research to generate 3 kW electricity [22]. So we took out the initial capital of USD 350 in our report. With 15,000 hours of lifespan. Again, Muhammad Umer Khan, Muhammad Hassan, M.Haseeb Nawaz, assumed 53 dollars as per ton of fuel cost [20].

4.2.4 Power Converter

The converter is used for the transfer of electrical power from AC-DC and DC- AC, respectively. As the performance from PV panels is in the form of DC which is used to transform DC to AC to feed electrical load of AC. the capital, replacement and operation and cost of repair and maintenance for 1 kW, which is respectively considered to be 900 USD, 900 USD and 90 USD [21]. The output of the converter is 90 percent and with a 15 year lifespan.

4.2.5 Batteries

One of the most essential and crucial parameters in power system operation is system reliability. Smooth operation is also required as solar and wind energy are both intermittent, and such elements' storage is essential. A 6V Li-ion battery with a nominal capacity of 1 kW and a lifetime of 15 years is used in our paper. With an initial capital ranging at around 300 dollars.

4.3 Sensitivity analysis

In optimal sizing procedure of Hybrid renewable energy para- meters such as fuel cost, wind speed, solar radiation, electricity price, and components cost does not have deterministic values. So,the uncertainty of these parameters has an effect on the simulation and optimization stages. These parameters are adjusted into HOMER with different values for a smoother simulation. In our study we have calculated with regard to solar radiation, wind speed and price per- tonne bio-gas fuel price for the simulation. For realistic simula- tion, the actual values may uctuate.

Chapter 5

Simulation Model

To achieve the most cost-effective and practical design of systems, HOMER Pro simulates all available and potential hybrid system configurations. HOMER Pro optimizes various combinations of NPC-based hybrid systems with the lowest-cost system on top. Figure 5.2 shows the simulation for the sensitivity cases we have already mentioned and figure 5.1 shows the most optimal cases.In figure 5.1 there are 10 rows each rows showing a different configuration and the other related cost values are also shown there . On section 6 we have pointed them one by one. We have taken the ***PV-Biogas generator -Battery*** system as the most optimal case because having a low COE of USD 0.176 with a NPC of USD 260022 . Then again sensitivity analysis give us much more practical idea about any design. It makes the system more reliable. In figure 13 we have shown the sensitivity cases for our optimal solution. where average solar radiation is taken as 4.65(kWh/m2/day), average wind speed 4.42 m/s and the biomass price(dollar per tonne =53) which carries COE USD 0.176 with a NPC of USD 260022 . Though in our optimal case wind energy is not a feasible solution so the effect of wind speed doesn't matter on that particular case.

PV (kW)	XL10	Biogas Gen (kW)	1kWh LI	Converter (kW)	Dispatch	Cost/NPC ($)	Cost/COE ($)	Cost/Operating cost ($/yr)	Cost/Initial capital ($)
31.2788526785524		49	66	23.5304405181845	CC	260021.6	0.1755538	13708.38	82806.25
28.0755760433621	1	49	99	22.0514253311582	CC	274322.7	0.1852092	12179.51	116871.9
		49	94	18.1458333333333	CC	283987.5	0.1917344	17923.5	52281.25
	1	49	61	19.1927083333333	CC	298680.8	0.2016546	17022.4	78623.44
		49			CC	361589.2	0.2441272	26643.88	17150
1.63541666666667		49		0.348958333333333	CC	364076.1	0.2458062	26685.45	19099.48
	1	49			CC	393980.7	0.2659963	26674.17	49150
1.63541666666667	1	49		0.348958333333333	CC	396520	0.2677107	26719.79	51099.48
374.106937955707	1		420	43.6763744792602	CC	728143.3	0.4918117	15372.46	529415.7
320.648112395717			738	45.730083498577	CC	764479.9	0.5165157	19731.15	509405.2

Figure 5.1: Optimization cases

Sensitivity/ Solar Scaled Average (kWh/m²/day)	Sensitivity/ Wind Scaled Average (m/s)	Sensitivity/ Biomass Price ($/tonne)	PV (kW)	XL10	Biogas Gen (kW)	1kWh LI	Converter (kW)	Dispatch	Cost/NPC ($)	Cost/COE ($)	Cost/ Operating cost ($/yr)	Cost/Initial capital ($)
4.2	3.5	45	31.73547212		49	67	23.41271058	CC	259969.3	0.1755184	13661.74	83356.91
4.2	4.420833333	45	31.73547212		49	67	23.41271058	CC	259969.3	0.1755184	13661.74	83356.91
4.650833333	3.5	45	32.71534977		49	65	24.02203316	CC	256317	0.1730526	13291.94	84485.18
4.650833333	4.420833333	45	32.71534977		49	65	24.02203316	CC	256317	0.1730526	13291.94	84485.18
4.2	3.5	53	32.33132369		49	67	23.4670273	CC	264180	0.1783613	13937.59	84001.65
4.2	4.420833333	53	32.33132369		49	67	23.4670273	CC	264180	0.1783613	13937.59	84001.65
4.650833333	3.5	53	31.27885268		49	66	23.53044052	CC	260021.6	0.1755538	13708.38	82806.25
4.650833333	4.420833333	53	31.27885268		49	66	23.53044052	CC	260021.6	0.1755538	13708.38	82806.25
5	3.5	53	32.36454263		49	103	23.23363957	CC	258112.7	0.174265	12924.98	91024.82
5	4.420833333	53	32.36454263		49	103	23.23363957	CC	258112.7	0.174265	12924.98	91024.82
4.2	3.5	60	33.19082379		49	66	23.332934	CC	267670.7	0.180718	14165.92	84540.46
4.2	4.420833333	60	33.19082379		49	66	23.332934	CC	267670.7	0.180718	14165.92	84540.46
4.650833333	3.5	60	30.28027066		49	64	23.86756366	CC	263575.5	0.1779532	14068.01	81711.08
4.650833333	4.420833333	60	30.28027066		49	64	23.86756366	CC	263575.5	0.1779532	14068.01	81711.08
5	3.5	60	32.51889451		49	72	24.14806236	CC	260941	0.1761745	13547.76	85802.15

Figure 5.2: Sensitivity cases(Solar radiation,Wind speed,Biogas fuel price)

Chapter 6

Results

In software analysis, HOMER simulates the configuration of different systems according to defined technical constraints and gives results based on the system's Net Present Cost (NPC).The NPC is calculated by [41]:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF_{(i,R_{Proj})}}$$

Where, $C_{ann,tot}$: Total annualised cost , i : discount rate , R_{Proj}: Project lifetime, $CRF_{(i,R_{Proj})}$: Capital Recovery factor.

6.1 Discussing about different hybrid configuration

From figure 12 we are observing different hybrid configuration and we noticed that the COE for these cases are between usd 0.176 to usd 0.517. Let's discuss about the figure 12 where we talked about the most optimal cases. There are 10 rows showing different configuration for our hybrid system and we will talk about them one by one.

6.1.1 Case 1

The **first** case is *PV, Bio-gas generator , Battery bank (1kWh)* system. In this case we are not considering the wind energy.The COE,NPC and OC on this case are USD 0.1755538 , USD 260021.6 and USD 13708.38 respectively.

6.1.2 Case 2

Then on the **second** case we took *all* renewable sources and observe the situation where we have taken PV, Bio-gas generator, Wind generator and the Battery bank (1kWh) . The COE, NPC, OC on this case are USD 0.1852092 , USD 274322.7, USD 12179.51 respectively.

6.1.3 Case 3

We eliminate PV and Wind energy system on the **third** case.The COE,NPC and OC for this case are USD 0.1917344 , USD 283987.5 and USD 17923.5 respectively. Comparing with the previous 2 cases here we are getting a comparatively large COE and in the next few cases we will see that it is gradually increasing.

6.1.4 Case 4

The **forth** case is a *Bio-gas, Wind energy and battery bank (1kWh)* design . And we are getting the COE,NPC and OC USD 0.2016546 , USD 298680.8 and USD 17022.4 respectively.

6.1.5 Case 5

In the **fifth** case *Bio-gas generator* is the only single source for meeting the load requirement. But from the figure 11 we can see that , the initial capital is the lowest for this case.The COE, NPC, OC on this case are USD 0.2441272 , USD 361589.2, USD 26643.88 respectively. But in this particular case we need to depend mostly on animal manure. But in case of hybrid design this is not very feasible that we are just confined to a single power source.

6.1.6 Case 6

The **sixth** case is *PV and Bio-gas generator* based design. Initial capital cost is also less for this particular case. Here we are getting the COE, NPC and OC USD 0.2458062 , USD 364076.1 and USD 26685.45 respectively.

6.1.7 Case 7

The **seventh** case is *Bio-gas generator and Wind energy* system. The COE,NPC and OC on this case are USD 0.2659963 , USD 393980.7 and USD 26674.17 respectively.

6.1.8 Case 8

On the **eighth** case we are considering *PV, Bio-gas generator and Wind energy* as source.The COE,NPC,OC on this case are USD 0.2677107, USD 396520, USD 26719.79 respectively.

6.1.9 Case 9

The **ninth** and **tenth** are worse cases. Where we need a very high value of initial capital. In the ninth case which is a *PV, Wind energy and Battery* system , the initial capaital is USD 529415.7 Having a large COE of USD 0.4918117 , we can not consider it as good optimal cases.

6.1.10 Case 10

As we already mentioned that **ninth** and **tenth** cases are not feasible in our are. In the **tenth** case we are observing a *PV and Battery* system . Which has a initial capital of USD 509405.2 and the COE is the most among all cases we described which is USD 0.5165157

6.2 Observation

However, in our located area, wind energy is not deemed as a feasible option. Because to produce electricity from wind energy we need a considerable amount of wind speed. In Bangladesh, we have used the wind in some particular areas where we are getting a decent wind speed value, particularly in the coastal areas, wind energy is very feasible. Yet, we try to test our hybrid design with wind facilities as our location is a sub-urban place, and there are lots of open space.

From the study of different cases as mentioned above, it is clear that a mix of **solar PV-Biogas generator-Battery** system appears to be the most optimal in terms of both economic and environmental aspects, because compared to other cases, all the values obtained here are the most beneficial. Then in **figure 5.2**, we have done the sensitivity analysis for the PV-Biogas-Battery system. If we look closely at the model, we have taken average solar radiation at 4.65(kWh/m2/day), average wind speed 4.42 m/s, and the biomass price(dollar per tonne =53), which carries COE USD 0.176 with an NPC of USD 260021.6. The initial capital is low for this particular case which is USD 82806.25. **Though** there are sensitivity cases for wind speed, but as our optimal system doesn't consider wind energy, there is no effect of wind energy on our pricing.

The regular renewable power output profile shows a rise from 6 AM to 6 PM. The battery's state of charge (SOC) is also growing throughout this period, following the solar PV power output

Table 6.1: Cost Summary

Component	capital ($)	Replacement ($)	O&M ($)	Fuel($)	Salvage ($)	Total($)
Autoset Genset	$17,150.00	$31,270.15	$47,470.62	$22,715.56	$3,437.38	$115,168.95
Generic 1kWh Li-lon	$13,400.00	$32,895.15	$8,661.44	$0.00	$1,563.40	$53,393.19
Generic flat olate PV	$31,735.47	$0.00	$4,102.61	$0.00	$0.00	$35,838.08
System Converter	$21,071.44	$8,940.06	$27,240.14	$0.00	$1,682.61	$55,569.03
System	$83,356.91	$73,105.36	$87,474.80	$22,715.56	$6,683.39	$259,969.25

pattern that forms a parabolic curve. From the **figure 6.1** shows that the graph of renewable power output and PV power output are quite identical. The Bio-gas generator operates at its rated capacity of about 7 PM.

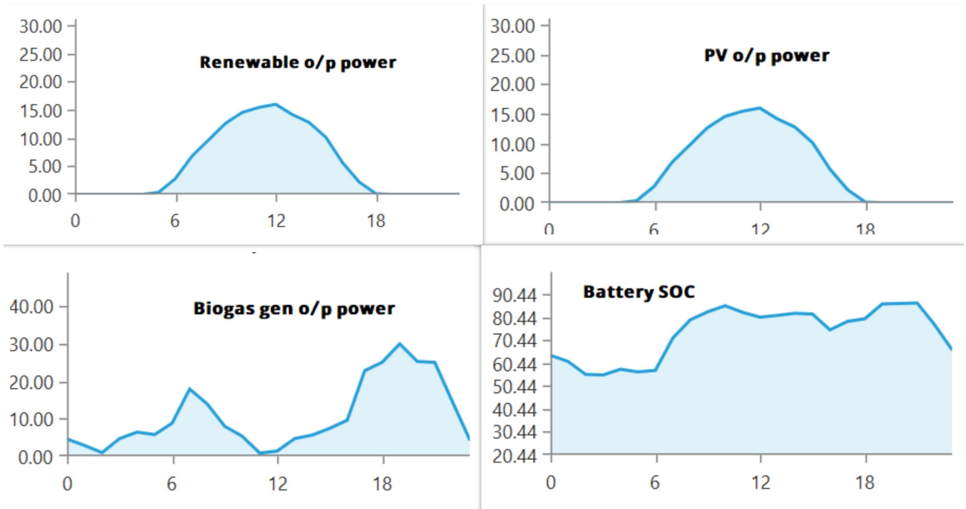

Figure 6.1: Daily profile for May

Table 6.1 shows the cost summary scenario, which provides the information about capital, replacement, operation and maintenance, fuel, etc., the cost for a different system. From table 6.1, we can observe that the high test total cost is for auto-set generators. This is obvious that there will be no fuel price for other systems that accept the generator. Again we have a high replacement cost for the battery.

The cost of capital in cash flow exists only during the project's erection, i.e., in year zero. As shown in Figure 6.2, there are constant operating and fuel costs for each year from the beginning of the project until the end of the project. Replacement costs are repeated nine times throughout the whole project. All these costs discussed above are cash outflows, while the project's salvage value is considered the cash inflow at the end of the project. Figure 6.2 displays the cash flow review for the 25 years of the project.For a given period, cash flow graphs physically reflect revenue and expenditure. Here we observe that for the 1st year, as we need to invest capital, the expenses are the highest.

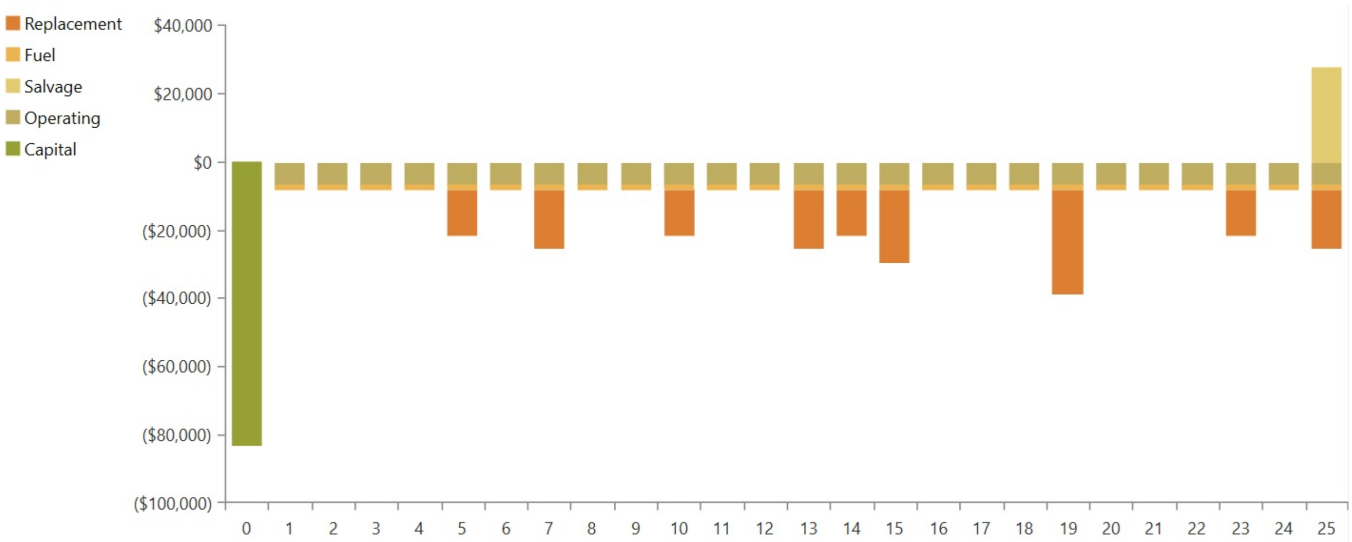

Figure 6.2: Cash Flow

Chapter 7

Conclusion

Renewable energy provides a clean and sustainable method for meeting the energy deficit facing Bangladesh and the world at large. In our paper we have created a homogenized system which is not localized and can be optimised for many other cases and geographic locations. However, the model we have optimized (Biogas generator, PV, Battery) in our paper has been fashioned in such a way that it is most suitable for implementation in the Bangladeshi energy sector. The model takes into account parameters such as COE, NPC and initial capital. The model primarily tackles the energy crisis caused by the influx of COVID-19 patients in makeshift isolation hospitals. However, the hybrid model is made in a way which can be easily modified to account for any load situation even after the pandemic situation is over. Most of the venues that has been modified for the makeshift hospitals were previously used for various business activities, so the hybrid model could be easily repurposed to meet their energy demand. Due to the booming population scenario that Bangladesh faces, the country always runs the risk of inadequate energy supply. If any such situations arise in the future, the model can then be repurposed to be a compliment to the current energy infrastructure. The model can also be used as a contingency plan for emergency situations where additional energy is required. At present, our model sets a milestone for meeting any energy inadequacy for the present and for the future.

Bangladesh sits in a unique geographical location which is perfect for efficiently utilizing renewable resources. Even though the government and various NGOs are currently working to integrate renewable energy to the existing power grid, most of these efforts are currently contained in the rural areas. In such areas the ultimate goal is usually to power a small house or a small community. The idea and implementation presented in our thesis addresses larger situations the ones already in progress in our country. As the location in our case study was on the outskirts of Dhaka, the model was fashioned in a way suitable to that area. Our study utilized the HOMER optimization system to analyze and find all possible outcomes and results. From these results we can choose the one that is best suitable for our case. Here, a hybrid solar PV, Bio-gas generator and Battery based system is found to be the most optimal case for the defined load, based on the large number of simulation results obtained from HOMER. Throughout this case, with respect to the other implementations considered, the price of COE, NPC, OC and initial capital is found to be less. Again in section 5 we have talked about the sensitivity cases. So, the ambiguity of some parameters (like fuel cost, solar radiation) affects the stages of simulation and optimization. For a smoother simulation, these parameters are modified in HOMER using different values. Although, there have been many interpretations of various hybrid system in our country, our paper provides a new insight into the optimized integration of a hybrid system that is specifically geared towards the healthcare sector.

7.1 Future Works

In Bangladesh, renewable energy integration is very insignificant even after having vast potentials. Currently a large percentage of the population is not connected to the power grid. In rural areas, the problem is more acute, as more than 50 percent of the residents are living without any access to electricity. The government and various NGOs can use our model to further integrate renewable resources to the power grid in future. Our current idea is geared towards the healthcare system. However, the model can in future be used to provide stable electricity to schools, business and residences.

Bangladesh is currently providing shelter to refugees in the southern border. The refugee camps can be powered using renewable energy. Our models also provide an opportunity to optimise and streamline the energy distribution in such camps.

7.2 Limitations of the Model

Even though our hybrid model is extremely flexible, the model does possess some setbacks. The model is heavily dependent on the sources. We realize that all the sources discussed in the thesis may not be available across all geographical locations. It is obvious that all geographical locations may not get sufficient sunlight or wind for solar and wind energy implementation and livestock presence for bio-fuel. This means that the hybrid model cannot function at its full potential. However, as the model is in not entirely dependent on any particular energy source, the other energy sources can be used to mitigate the lack the particular energy source. Though, the model we have presented for Purbachal is currently cost efficient with increasing urbanization in the area, the cost to benefit ratio may not be sustainable in the long run

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