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DEVELOPING A MICROGRID SYSTEM FOR BUYUKADA ISLAND IN ISTANBUL

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Developing A Microgrid System For Büyükada İsland in İstanbul

Büyükadada (İstanbul) Bir Mikro-şebeke Sistemi Geliştirilmesi

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ABSTRACT

There is a strong link between access to energy and overall quality of life. Currently, around 1.4 billion people worldwide do not have access to electricity. Microgrids become a reality as a result of the massive shifts that have occurred in the energy sector over the last few decades. The micro grid concept anticipates a large number of loads and smaller-scale sources working together as a single controlled system providing both electricity and heat to its neighborhood. Microgrids can be used in a decentralized mode to offer complete control over the energy in a small region, or in a grid-connected mode to supply backup power to the national grid.

Among the numerous islands around Istanbul, Büyükada is the fourth largest and most populous, and energy is provided beneath the water from the metropolis. In this regard, it is conceivable to deploy micro grid systems on this island in order to utilize renewable energy sources in Büyükada. Initial research revealed the island's potential for renewable energy sources. Solar, wind, and biomass demonstrated to have sufficient capacity to meet the energy demands.

The study's goal is to evolve renewable energy, create a microgrid, and determine the most efficient and cost-effective approach to supply the island's needs. Environmentalists advocate for the use of renewable energy as a result of global warming, CO_2 emissions, and the need for green and sustainable energy. The micro grid is one of the greatest choices for powering islands like Büyükada and extending the idea for the future chain of Micro grids.

After using Homer Pro for designing and optimizing the microgrid which is around 128 million $ for a levelized cost of energy (LCOE) 0.2$/KWh which consists of PV panels, wind turbine, biogas generator, battery systems and a diesel generator for reducing the price around 85% renewable, however another microgrid is taken into account which is 100% renewable energy but the price is almost triple the price around

338 million $ with 0.53$/KWh for LCOE. All the details are mentioned in the chapter of methodology and the chapter of results.

ÖZET

Enerjiye erişim ile genel yaşam kalitesi arasında güçlü bir bağlantı bulunmaktadır. Şu anda dünya çapında yaklaşık 1,4 milyar insanın elektriğe erişimi bulunmamaktadır. Mikro şebekeler, son yıllarda enerji sektöründe meydana gelen büyük değişimlerin sonucu olarak önemli bir konuma gelmiştir. Mikro şebeke konsepti, lokal olarak hem elektrik hem de ısı sağlayan tek kontrollü sistem olarak, birlikte çalışan çok sayıda yükü ve daha küçük ölçekli kaynakların birlikteliğini öngörmektedir. Mikro şebekeler, küçük bir bölgedeki enerji üzerinde tam kontrol sağlamak için merkezi olmayan bir modda veya ulusal şebekeye yedek güç sağlamak için şebekeye bağlı bir koşulda kullanılabilmektedir.

İstanbul çevresindeki çok sayıda ada arasında en kalabalık ve yüz ölçümü açısından dördüncü sırada yer alan Büyükada'ya enerji İstanbul'dan deniz altı yoluyla sağlanmaktadır. Bu bağlamda, Büyükada'da yenilenebilir enerji kaynaklarından yararlanarak bir mikro şebeke sisteminin kurulmasının uygun olabileceği düşünülmektedir. Çalışmanın ilk aşamasında adanın yenilenebilir enerji kaynakları potansiyelini ortaya çıkarılarak, güneş, rüzgar ve biyokütle enerjisinin gerekli enerjiyi karşılamak için yeterli kapasiteye sahip olduğu gösterilmiştir.

Bu çalışmanın kapsamında yenilenebilir enerji kullanımını geliştirmek, bir mikro şebeke oluşturmak ve adanın ihtiyaçlarını karşılamak için en verimli ve uygun maliyetli yaklaşımı hedeflenmektediler. Çevre konularında çalışan bilim insanları küresel ısınma, CO_2 emisyonları karşısında yeşil ve sürdürülebilir enerji ihtiyacının bir sonucu olarak yenilenebilir enerji kullanımını savunmaktadırlar. Mikro şebeke, Büyükada gibi adalara enerji sağlamak ve gelecekteki mikro şebekeler zinciri fikrini genişletmek için en iyi seçeneklerden biri olarak öngörülmektedi.

Çalışmada Fotovoltaik güneş panelleri, rüzgar türbini, biyogaz jeneratörü, akü sistemleri ve bir dizel jeneratörden oluşan bir sistemi tasarlayıp, optimize etmek için Homer Pro program kullanılarak, %85 oranında yenilenebilir enerji kullanılan mikro

şebeke sisteminde seviyelendirilmiş elektrik maliyeti (LCOE) 0.2$/KWh birim fiyatı ile 128 milyon $, %100 yenilenebilir enerji olan başka bir mikro şebeke ile kıyaslandığında LCOE için fiyatı 0,53$/KWh birim fiyatı ve 338 milyon $ ile fiyatın neredeyse üç katına çıkabildiği ortaya konulmuştur.

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LIST OF SYMBOLS/ABBREVIATIONS

LCOE: levelized cost of energy

μG / MG: microgrid

IoT: internet of things

CERTS: The Consortium for Electric Reliability Technology Solution

DER: distributed energy resources

LV: low voltage

OPEC: The Organization of Petroleum Exporting Countries

YEKDEM: Renewable Energy Support Mechanism

EMRA: Energy Market Regulatory Authority

AC: alternating current

DC: direct current

EGS: Enhanced Geothermal Systems

CHP: combined heat and power

BEPA: Biomass Energy Potential Atlas

IEA: International Energy Agency

DG: distributed generation

kg: Kilograms

kW: Kilowatt

kWh: Kilowatt-hour

MW: Megawatt

WPP: Wind Power Plant

HV: high voltage

MV: medium voltage

HFAC: higher frequency Alternative Current

LFAC: line frequency Alternative Current

LVDC: Low-voltage direct current

IRECG: The Catalonia Institute for Energy Research

PEV: plug-in electric vehicle

PCC: Point of common coupling

HOMER: Hybrid Optimization of Multiple Electric Renewables

GHI: global horizontal irradiance

1. INTRODUCTION

The microgrid (μG) concept envisions a collection of loads and smaller-scale sources (<100 kW) cooperating as a single controlled system that provides both electricity and heat to its neighborhood. This concept provides a new perspective on categorizing the activity of the circulating age. The microgrid may be viewed as a controlled cell of the electricity system by the utility. For example, this cell might be managed as a single dispatchable load (island mode), capable of responding in seconds to transmission system problems. The microgrid can be designed to fulfill the client's specific demands, such as improving local quality, lowering feeder losses, supporting local voltages, increasing efficiency through waste heat utilization, voltage sag correction, or providing uninterruptible power supply features. Some old and new techniques could be integrated to control the microgrid such as IoT (internet of things), fuzzy logic, machine learning…

Furthermore, there are two sorts of systems that may be connected to or disconnected from the grid. So, grid-connected systems operate in a two-way relationship, however when there is extra energy that is not required, it is sent to the city grid, and if the system has no production and a high need for energy, it is drawn from the main grid. The electricity received and the electricity supplied by the grid are both measured with a bidirectional meter which can measure the flow of electricity in two directions, and it is connected to the system.

Due to toxic fossil fuels on environment and the increasing awareness technologies in renewable energy, the microgrids get more interest by time.

1.1 Literature Review

R. H. Lasseter in [1] produced the first scientific study connected to microgrid, in which the basic design, control and protection, and energy management of microgrid are defined.

T. Ackermann et al [2] established distributed generation. It has examined the relevant difficulties as well as described and explained distributed power production. They defined the phrase "distributed generation." Furthermore, technical terminology such as distributed capacity, distributed resources, and distributed utility have been covered.

R. H. Lasseter et al [3] addressed the technologies of MGs in depth in their work connected to the research project "The Consortium for Electric Reliability Technology Solution (CERTS)," which became the cause for MG development. This study also informs readers on the technology utilized to launch distributed generating.

The researchers have covered almost all of the major types of distributed energy resources, including storage, equipment load control, and heat recovery. A MicroGrid system's major characteristic is that its power sources are linked to controllers. The paper by N.Hatziargyriou et al. [4] includes information on ongoing research and development while also illustrating the function of microgrid operation, which is now used in many developed nations across Europe, Japan, the United States, and Canada. MGs allow incredibly decentralized DER coordination (distributed energy resources). As a result, MGs reduce the control pressure applied to the grid. According to the authors, microgrids are low voltage (LV) locally managed clusters of DERs that function as a lone producer or both in electric and energy markets on behalf of the grid. Although a microgrid runs securely and efficiently inside its own local distribution network, it is vulnerable to "islanding."

S. Chowdhury et al. [5] investigate the fundamental concept, producing technologies, impacts, operation, control, and management features, as well as the economic feasibility and market participation problems of MG and active distribution networks. Microgrids are referred to as active distribution network systems by the authors because when distributed energy resources are linked into power systems, the distributed network becomes active.

H. Jiayi et al. [6] investigated the basic concepts of MGs and their active distribution networks, as well as their needs, technical advantages and disadvantages, and other management and operational difficulties. The authors investigate the basic principles governing the operation of numerous DER technologies used in Microgrid, as well as its active distribution networks, and how this affects the whole notion of Microgrid. Microgrids have a considerable influence on both the main grid and its customers.

M. Barnes et al [7] provide a summary of global MG studies in their publication. Authors have provided a brief description of the MG structure. Following an evaluation, the hardware range and control choices for Microgrid operation are offered. The study evaluates and highlights the operational principles and significant components of the previous research and field experiments.

F. Martin-Martnez et al. [8] compiled a review of the literature on MGs in their study. The writers represent MG's fundamental concepts, structure, and architecture. Each MG physical layer has been thoroughly examined in this paper. In the study, there is discussion on AC and DC forms of MG operation, evaluation of DC voltage, and comparison of different technologies included in the MG principle.

Types of MG have been introduced by A. Zafeer et al. [9]. The study discusses methodology as well as simulation outcomes. The consequences of coordinating energy demands and energy sources inside a single MG mechanism.

For Büyükada, E. Leblecioğlu carried out the wind farm micro-positioning study using the Windsim program. Büyükada has chosen two 2 MW turbines. He calculated the capacity factor as 24% [52].

In 2019 work, A. Gülay developed an offshore wind farm for Gökçeada and Gaziköy. Based on data from the meteorological observation station, it was determined that the "VESTAS V116-2.0 MWIEC IIB" wind turbine is the best fit for the region. A. Gülay discovered that Gökçeada is appropriate for an offshore wind farm as a consequence of his research [53].

Ioannis Kougias and colleagues discovered in 2019 that the islands of Rhodes, Lesvos, Chios, Karpathos, and Patmos were not linked to the grid energy. Most of these islands' power is generated by fossil fuels. Using the Harmony Search Algorithm, they calculated the islands' electrical consumption between 2016 and 2036. They investigated wind, solar, and storage possibilities by analyzing each island separately, and discovered that wind was the best suited energy source [54].

B. Güzel et al. (2012) evaluated prospective energy production opportunities in the open sea offshore Bozcaada and Gökçeada in 2012. They conducted an economic analysis of the off-shore wind farm's potential to generate power in the open sea. In their study, they determined that if the “1.8 MW Vestas” turbine with a 100 m body height is selected for the Bozcaada region and if domestic production is made, it will be suitable for investment [55].

R. Ahshan and his colleagues implemented micro wind turbine applications and discovered that the turbine's payback period is rapid at locations with less than 1 kW and is sufficient to fulfill home power needs [56].

M. Shafiq and colleagues looked at the yearly energy output and capacity factors of small, medium, and large turbines in five distinct areas [57].

2. THE RENEWABLE ENERGY OUTLOOK

From the oil crisis to the renewable energy revolution, there has been a shift in the energy landscape. In 1973 The Organization of Petroleum Exporting Countries (OPEC) oil crisis cut off the energy streams just as the current oil and debt-fueled consumer age was gaining traction in wealthy industrialized countries. As the globe grapples with the challenges of making a quick transition away from fossil fuels in the coming decade. As a direct outcome of a crisis, great invention can arise. The oil crisis demonstrates how a crisis may lead to government-led energy conservation and the emergence of a new economy based on renewable energy. In numerous European nations and North America, scientists, environmental activists, and innovators converged on the notion of harnessing the wind, sun, and geothermal hot water to generate power for residential use. None of these technologies were novel, but they were all experimental or restricted in use, such as wind-powered water pumps in rural areas of the United States, alternative fuel vehicles, and, ironically, solar panels above oil rigs. With hindsight, these green shoots appear to represent the beginning of the worldwide renewables sector that we see today [51].

2.1 Turkey’s Energy Overview

Energy is one of humanity's most pressing challenges today. Energy is a crucial requirement for supporting life and preventing it from being disrupted. Although everything around us needs energy. Energy is an essential in every aspect like transportation, communication, lighting and production and it has the influence straight on the level of societies. Energy is the fundamental resource to develop the economy of every country if it is going to develop in a linear way. If there is an outage of energy in any country, it is not possible to talk about the level of development in that country because any society nowadays cannot survive without energy.

There are two types of energy sources, the renewable and non-renewable. Meanwhile the renewable sources such as solar, wind energy, hydroelectric energy, geothermal energy, biomass energy, and tidal energy, however, the non-renewable sources such as coal, oil, natural gas and nuclear energy.

Sustainable energy, which stays at low levels as far as productivity, is subject to trend setting innovation, becomes a force to be reckoned with step by step particularly with the improvement in speculations and technological expenses. For this reason, significant legitimate advances and motivations are continuous to create power from environmentally friendly power [10].

Rather than deciding which type of energy to utilize, states' role in this evolution has been to pick which energy type to support and which generation technology to promote through government-supported scientific research and development. The installed power of power plants in Turkey at the end of October 2021 is presented in Table 2.1 [11].

Table 2.1 Distribution of Licensed Electricity Installed Power by Source as of The End of October 2021 (MW-%)

	2021 October	
Resource Type	Installed Power (MW)	**Ratio (%)**
Natural Gas	25.473,16	**27,80**
Dam Hydraulıc	23.279,92	**25,40**
Wind	10.179,76	**11,11**
Lignite	10.119,92	**11,04**
Imported Coal	8.993,80	**9,81**

Stream	8.178,60	**8,92**
Geothermal	1.651,17	**1,80**
Biomass	1.436,70	**1,57**
Solar	854,83	**0,93**
Coal	810,77	**0,88**
Asphaltite	405,00	**0,44**
Fuel Oil	251,93	**0,27**
Oil	4,74	**0,01**
Lng	1,95	**0,00**
Diesel	1,04	**0,00**
Total	**91.643,27**	**100,00**

Table 2.2 Distribution of Licensed Electricity Production By Source In October 2021 (MWh %)

	2021 October	
Resource Type	Production (Mwh)	**Ratio (%)**
Natural Gas	10.684.038,42	**42,27**
Lignite	3.683.886,18	**14,57**
Hydraulic	3.271.308,49	**12,94**
Imported Coal	2.720.834,41	**10,76**
Wind	2.622.140,16	**10,37**
Geothermal	939.797,07	**3,72**
Biomass	680.776,16	**2,69**
Coal	286.813,20	**1,13**
Asphaltite	191.995,47	**0,76**
Solar	164.957,12	**0,65**
Fuel Oil	31.681,30	**0,13**

Diesel	0,00	**0,00**
Total	**25.278.227,97**	**100,00**

As shown in tables 2.1 and 2.2 above, the total installed capacity of power plants in Turkey at the end of October 2021 is 91.64 GW, with natural gas accounting for 27.8 % of this power, hydro accounting for 25.4 %, lignite accounting for 11.04 %, and renewable energy accounting for 15.41 % (wind, solar, geothermal and biomass). Wind contributes 10.37 % of total yearly generation in Turkey, solar contributes 0.65 %, geothermal contributes 3,72 %, and biomass contributes 2.69 %. Renewable Energy Support Mechanism (YEKDEM) has been supported to electricity production by renewable energy since 2010 and installed electricity capacity of Turkey will be calculated over 109 MWe in 2023 by Energy Market Regulatory Authority (EMRA). Within the scope of the Kyoto Protocol, which takes into account global warming and environmental pollution, The government purchase guarantee was put in place with the help of Turkey's strong focus on renewable energy projects.

2.2 The Capacity Factors of Renewable Power Plants

The yearly maximum generation amount is used as the basis for calculating the annual electricity producing amount mentioned in the power plants' associate degree and generation licenses. The generating quantity in Table 2.3 [11] corresponds to the corresponding capacity factor in other renewable energy sources.

Table 2.3 Capacity Factors of Generation Resources and Generation Quantities

The Source	Hour	Capacity Factor (%)
Wind	4000	45

Solar	2000	22.8
Biomass	7500	85
Geothermal	8000	92

When actual generation in the generation facilities exceeds this value or the measurement and / or feasibility results are certified by an accredited institution, the amount of generation corresponding to the capacity factor in the measurement and / or feasibility results is based on the amount realized. There is a maximum amount that can be manufactured under the EMRA's rule, but it is permitted on the condition that it can be generated on top of it.

2.3 Renewable Energy Systems

Renewable energy is defined as energy that is obtained directly or indirectly from natural sources and is thus sustainable. Solar energy, hydraulic energy (water power), geothermal energy, wind energy, biomass, and waste energy are all examples of renewable energy sources.

As a consequence of the effect of gases such as carbon dioxide, carbon monoxide, methane, and nitrogen oxide, which are discharged into the atmosphere by fossil energy sources such as coal, petroleum, natural gas, tar, and related chemicals, a variety of environmental challenges have arisen. To begin, there are concerns that present the same issue under several titles, such as global warming, climate change, air pollution, and the greenhouse effect. The use of fossil fuels results in economic foreign dependency and high import costs, while their finite supplies diminish their sustainability performance. Aside from fossil fuels, it is certain that negative attitudes and behaviors toward nuclear energy will prevail in the coming years. Despite these concerns, growing environmental awareness in recent years has resulted in cleaner, more sustainable environmental understanding, as well as a shift toward renewable energy sources for environmental problem solutions.

Renewable energy sources are expected to meet a major amount of the world's energy demands in the future century. On the one hand, the extinction of fossil fuels, their impact on environmental issues, and their high cost make renewable energy sources more attractive than fossil fuels.

2.3.1 Wind Energy

When an air mass heats up more than its current temperature, it rises above the atmosphere, and the mass of cold air in the same volume settles into the vacated area. The displacement of these air masses is caused by wind. Wind, in other words, is the flow of air from a high-pressure center to a low-pressure center induced by pressure differences between two adjacent pressure zones. Winds move from high to low pressure zones and are impacted by a variety of elements including the earth's rotation around its axis, surface friction, local heat dissipation, various atmospheric events in front of the wind, and the topography of the land. Wind qualities vary over time and locally due to local topographical variations and inhomogeneous heating of the ground. Wind speed and direction are the two criteria used to measure it. Wind speed increases with altitude, and theoretical power increases proportionally to the cube of its speed.

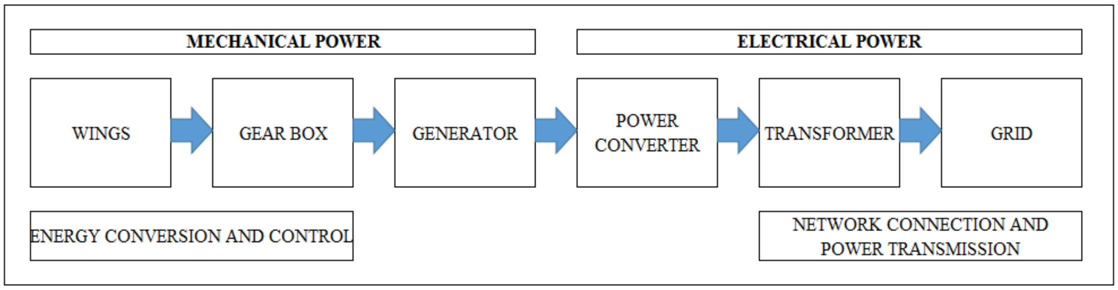


Figure 2.1 Wind Energy Conversion Stages

It might be created by mounting wind generators atop towers and harnessing high electrical energy from the wind. The turbines are moved by the incoming air, and the generator is powered by the shaft to which the turbine blades are attached. Cables carry the electrical energy generated by the wind turbine tower to the energy panel. Wind turbines may be oriented to face the oncoming wind and are operated automatically by mechanical or power electronic circuits. To minimize damage in high-speed winds, the wings may move along their own axis and can be slowed. In order to gain the highest efficiency from wind power plants, wind turbines should be situated where the wind speed exceeds a certain average and continuous yearly wind speed.

Wind power is a sun-derived natural, renewable, clean, and limitless energy source. A little percentage of the energy provided by the sun to the globe gets turned to wind energy. Air movement is caused by the temperature and pressure differential that emerges as a result of the sun not heating the ground surface and atmosphere equally. Aside from the constraints of wind energy applications, such as high initial investment prices, restricted capacity factors, and unpredictability of energy output, as shown below:

• It is plentiful and unrestricted in the atmosphere.

• It is an ecologically friendly renewable and clean energy source.

• Its source is dependable, with no fear of exhaustion or price increases over time.

• Its cost has dropped to the point where it can compete with today's power plants.

• Low maintenance and running costs.

• It generates jobs.

• Because its raw materials are entirely local, it does not rely on foreign sources.

• Its technology is quite simple to install and operate.

• Commissioning may be completed in a short period of time [12].

Wind turbines are being used to power many contemporary constructions all around the world. Wind turbines may provide electricity for an extended period of time. They have a life expectancy of 20-40 years, however this is not definite. Many wind turbine research and tests have been carried out, and it is thought that the best turbines for today's conditions are those with a tubular tower, three blades, and generators.

Wind turbine applications are classified into three types. Grid-connected alternating current (AC) applications are the earliest of these, and they deliver all or part of the energy generated by wind turbines to the national electrical grid. The second application is direct current (DC), which is accomplished by directly providing electricity to a site via wind turbines, independent of the national electrical grid. The third use is remote DC system applications, which are used to meet the electrical energy needs of places like meteorological stations, railway signalization, lighthouses, and fire watch towers [13].

2.3.1.1 Wind Energy Outlook

The generation of wind energy is increasing on a daily basis. While the world's installed wind power capacity was 2,160 MW in 1990, it has grown substantially since then, reaching 18 GW in 2000, 93 GW in 2007, and 750 GW in 2020, according to the International Energy Agency, 2021 [14].

Wind energy has the fastest growth rate of any known energy source, with an average annual increase of 15-20 percent. Its share of overall energy use is increasing, although it is still insufficient today. Table 2.4 [15] shows the countries with the highest wind energy capacity.

Table 2.4 Countries with the Highest Capacity in Wind Energy in 2020

	Countries	Power Capacity (Mw)
1	China	281,993
2	European union	201,507
3	USA	117,744
4	Germany	62,184
5	India	38,559
6	Spain	27,089
7	United Kingdom	24,665
8	France	17,382
9	Brazil	17,198
10	Canada	13,577
11	Italy	10,839
12	Sweden	9,688
13	Australia	9,457
14	Turkey	8,832
15	Mexico	8,128
16	Netherland	6,600

Despite the fact that wind energy accounts for a relatively small portion of the world's overall energy demand, investments in wind energy are significantly higher than the global average. Wind energy, like other renewable energy sources, is gaining popularity year after year.

Wind energy uses wind turbines to transform the kinetic energy of the wind into mechanical energy, which is subsequently converted into electrical energy.

The strength of the wind varies according to its speed, the cross-sectional area through which it flows, and the density of the air. As you ascend above sea level, the pressure lowers and, as a result, the wind's force reduces.

In Turkey, as in the rest of the globe, fossil fuels are mostly used to meet energy demands, and natural gas and oil supplies are insufficient. Electricity shortages caused by oil crises, as well as the abundance of renewable energy sources, have boosted development in this field in the past.

Turkey's total wind energy potential is estimated to be between 40,000 and 80,000 MW. Unless otherwise noted, according to official meteorological station data, Turkey's annual average wind speed is 10 meters in height 2.54 m/s and wind power density is 24 W/m2. When it comes to assessing Turkey's wind energy potential by region, the Marmara and Southeastern Anatolia region looks to be wealthier than the others [16].

2.3.2 Solar Energy

Because it is the principal source of fossil and hydraulic energy and heats our globe, solar energy is the most significant renewable energy source. The dispersion of energy that occurs in space during the conversion of hydrogen to helium is referred to as the sun's energy. Because the sun will continue to shine for millions of years, it will give our planet with a limitless amount of energy. The Sun, directly or indirectly, serves as the foundation for all energy sources on the planet. The sun's beams provide 170 billion MW of energy to the planet. This figure is 15,000-16,000 times the entire amount of energy utilized by humanity on the earth today. There are two approaches to evaluate the solar energy that is now reaching the Earth. There are two types of conversion: heat conversion and electrical energy conversion. Collectors are used to convert solar energy to heat energy; solar cells are used to convert solar energy directly to electricity. Solar cells have been employed in the conversion of solar energy to electrical energy [17].

The usage of heat from solar energy, in particular, has risen in relevance in today's technical and economic climate. Solar energy, which is not commonly used but is the most potential energy source for the future, is converted into electricity using two unique methods: direct conversion and indirect conversion. It is not widely used, but it is the most valuable energy source for the future in terms of generating electrical energy using various technologies, as well as applications in which different thermal effects are used to heat and cool utilizing this energy.

Solar cells are devices that convert solar energy directly into electricity without creating any noise, harming the environment, or requiring a moving mechanism. From the dawn of time to the present, people have observed and experienced the benefits of solar energy. In theory, the sun was used to transform heat energy. Solar heat conversions are the oldest and most important technological way of exploiting solar electricity for this purpose. Nowadays, the increased use of solar energy aids in minimizing and reducing the consumption of fossil fuels.

Photovoltaic solar cells, which convert solar electricity directly into electricity, are becoming increasingly used in solar energy power plants. Solar cells, which were originally used on micro scales such as wrist watches or calculators, have now spread to a broader variety of applications such as automobiles, solar plants, and plants. Prices fell as the product grew more popular.

2.3.2.1 The World Solar Energy Outlook

Despite the fact that photovoltaic solar cell power systems are now more expensive than other electrical energy generating systems, they are thought to be systems that will contribute more to power generation in the near future, and substantial research and studies are being undertaken on the issue all over the world. Solar PV installed capacity is around 800 Gwe in the world (2020).

It is feasible to create a different estimate based on the nations that use solar energy. Table 2.5 displays the leading nations in solar energy technology, as well as their installed capacity as of the end of 2020 [58].

Table 2.5 Top 15 Countries Installed Solar Energy in the World till 2020.

	Countries	**Installed Capacity (Mw)**
1	China	254,355
	US	75,572
	Japan	67,000
2	Germany	53,783
	India	39,211
3	Italy	21,600
4	United Kingdom	13,108
5	Australia	17,627
6	Vietnam	16,504
7	South Korea	14,575
8	Spain	14,089
9	United Kingdom	13,563
10	France	11,733
11	Netherland	10,213
12	Brazil	7,881
13	Turkey	6,668
14	South Africa	5,990
15	Taiwan	5,817

Although the future looks hopeful, it does not properly satisfy those who are concerned about energy conservation and the utilization of renewable resources. These groups will benefit from a greater preference for solar energy-based technologies, and it is also critical to grasp the worth of the energy that nature provides us.

2.3.3 Geothermal Energy

The heat of hot rocks and fluids at the depths of the earth's crust reaches the ground through weak layers, resulting in geothermal energy. Because the liquids that make up the geothermal fluid are of meteoric origin, the subsurface reservoirs are continually supplied and the source may be refilled. As a result, unless there is over-nutrition consumption, there is no expiration of geothermal resources in practice. If the geological circumstances remain stable, the reinjection procedure is carried out, and the nutritional-generation values are met, geothermal reservoirs generated by rain, snow, sea, and magmatic fluids feeding porous and fractured rock masses underground preserve their renewable and sustainable qualities. Geothermal energy becomes renewable as a result of this cycle.

Until the beginning of the twentieth century, the regions of use of geothermal resources, which were utilized for the purpose of cooking health and food, were limited. However, as technology has advanced, the areas of use of geothermal resources have grown more extensive and diverse. Among these include energy generation, heating, and many industrial applications.

Geothermal energy is used to create power in settings where the temperature is sufficient. Although classifications vary by country, geothermal energy is typically split into three kinds based on temperature content:

- Fields at Low Temperatures (20-70 ° C)

- Fields of Medium Temperature (70-150 ° C)
- Fields with high temperatures (over than 150 ° C)

Low and medium temperature regions, notably in heating (greenhouse, building, agricultural applications), industry (food drying, timber, paper and weaving industries, leatherwork, cooling facilities), and chemical production, are currently under technical and economic pressure (boric acid, ammonium bicarbonate, heavy water, dry ice from CO2 in the fluid). On the other hand, technologies for producing electricity from fluids in medium enthalpy fields have been developed and presented. Fluid generated by high enthalpy fields may be used in a number of purposes, including energy generation.

2.3.3.1 Geothermal Energy World Outlook

Geothermal energy offers several advantages in terms of size, environmental friendliness, and cost; the same fluid may be utilized for various uses at the same time; it is safe; it provides jobs; and the resource can be exploited according to seasonal need. Furthermore, the advantages of greenhouse heating and organic formation are unaffected by weather circumstances, their influence on CO_2 emissions reduction, or the global relevance of geothermal energy.

Asia-Pacific and South America have the greatest potential for geothermal energy. These two locations account for over 60% of the world's geothermal energy potential. In Asia-Pacific, the top nations in terms of geothermal energy potential are Indonesia, the Philippines, Japan, and New Zealand; in South America, the top countries in terms of geothermal energy potential are Colombia, Ecuador, Chile, Peru, Bolivia, and Argentina. Italy and Turkey have significant geothermal resources in Europe; the United States has significant geothermal resources in North America; and Kenya, Zimbabwe, and Ethiopia have significant geothermal resources in Africa [18].

There are various geothermal power production technologies such as; binary, flash, multi-flash, bottoming cycle, dry steam, Enhanced Geothermal Systems (EGS).

According to statistics, the globe has 16 GW of installed geothermal capacity to electricity production. This figure amounts to around 0.5 percent of overall renewable energy generation. The United States has the most installed capacity in geothermal energy. The United States accounts for around 30% of overall geothermal capacity. Turkey ranks first in the list of capacity installed by geothermal energy in 2020, with 1549 MW.

Table 2.6. [19] lists the top 10 nations in the globe in terms of installed geothermal capacity.

Table 2.6 Ten nations having the most installed geothermal power generation in 2020

	COUNTRIES	**INSTALLED POWER (MW)**
1	US	3700
2	Indonesia	2,289
3	Philippines	1,918
4	Turkey	1,549
5	Kenya	1,193
6	Mexico	1,105
7	New Zealand	1,064
8	Italy	916
9	Iceland	755
10	Japan	550

Geothermal resource-based generating plants require a license. A private company or public institution with a business license can assign the rights to this site associated to the business license-based use zones to another firm or public institution through a leasing arrangement. Geothermal resources have a greater cost of increased resource use by public bodies through tenders.

The geothermal reserves generated by rain, snow, sea, and magma fluids feeding porous and fractured rock masses underneath are renewable and sustainable as long as the subsurface and reinjection conditions stay stable.

They are unaffected by short-term atmospheric conditions. Reinjection is the technique of returning geothermal fluid to the environment after it has served its purpose of generating drilling and feeding geothermal reservoirs. Many countries have made rejection a legal requirement [19].

2.3.4 Biomass and Waste Energy

Biomass fuels are solid, liquid, and gaseous fuels obtained from agricultural and forest products, as well as processing residues including vegetable wastes, agricultural harvest leftovers, and organic wastes.

Bioenergy, whether as a solid fuel (biomass), a liquid (biofuel), or a gas (biogas or biomethane), may be used to provide basic needs like heating, cooking, and water heating. Bioenergy on a bigger scale; in addition to meeting the heating demands of residential, public, and commercial buildings, it may be used to generate electricity and heat in tandem, combined heat and power (CHP) systems for commercial usage as well as combined.

Wood, charcoal, animal excrement; agriculture and forestry industry organic wastes, fermentation of alcohol and methane; Biomass energy refers to energy derived from biological sources such as diverse aquatic plants. In a nutshell, biomass energy is derived from organic materials in a variety of methods.

Firewood, charcoal, and animal dung are the earliest known raw materials for this energy, which is usually utilized for heating. In addition to the biomass energy obtained through the traditional burning method. By converting solid agricultural, gas, and liquid fuels into biomass fuel, heat, and electricity utilizing combustion processes from energy farming products, urban wastes, agricultural industrial wastes, or other approaches, biomass fuel, heat, and power may be obtained [20].

The Ministry of Energy and Natural Resources has created a "Biomass Energy Potential Atlas (BEPA)" in order to fully use biomass energy. Biomass has been defined as an energy source by BEPA as animal waste, vegetable waste, urban garbage, and forest waste.

The sun is the source of energy stored chemically in plants during photosynthesis, particularly in the form of cellulose, and which may later be utilized in a variety of ways. Solar energy conversion into stored energy in the form of biomass is important for human life. While photosynthesis produces the organic components that serve as the energy source, it also produces the oxygen that all living beings require to breathe. On the other hand, the carbon dioxide produced by the combustion of organic materials was absorbed from the atmosphere during their creation, and the environment will be protected in terms of carbon dioxide emissions during the generation of energy from biomass.

In Turkey, biomass is frequently burned directly. After many treatments such as anaerobic digestion, pyrolysis and fermentation, gasification, hydrolysis, biophotolysis, and esterification reaction, biomass is infrequently burned to improve fuel quality. Biogas is a colorless, odorless, lighter-than-air, brilliant blue flame-burning gas created by the fermentation of organic-based wastes/residues in an oxygen-free environment (anaerobic), depending on the nature of organic compounds; it is a gas combination comprising 40-70 percent methane, 30-60 percent carbon dioxide, 0-3 percent hydrogen sulfide, and very little nitrogen and hydrogen [20].

There will be two approaches to biomass energy: classical and modern. First, conventional forest firewood and plant and animal waste (such as dung) are utilized as fuel. The second kind is contemporary biomass energy, which includes energy forestry and forest-tree industry wastes, agricultural vegetable wastes, urban wastes, and agricultural-based industrial wastes.

Biogas is a flammable gas with a high heat value produced by anaerobic (oxygen-free) bacteria in tanks designed to hold air at a fixed temperature from diverse vegetal, animal, and human wastes generated as a result of agricultural production. In other words, it's made up of 60-70% methane, 30-40% carbon dioxide, and a trace quantity of hydrogen sulfide, hydrogen, water vapor, ammonia, carbon monoxide, and nitrogen, all of which are produced by the fermentation of organic material like biogas, plant, and animal waste in an oxygen-free environment. is a flammable colorless gas combination. Biogas has a thermal value that fluctuates depending on the methane ratio in its composition, but it normally ranges from 4700 to 6000 kcal/m3. As a result, it's an energy source that may be used as a replacement for traditional energy sources in applications including heating, lighting, and water heating [21].

The use of biomass in the production of electrical energy can take the shape of rotating turbines and the generation of electricity from generators by extracting steam from the heat created by directly burning organic materials, in a manner similar to thermal power plants. Furthermore, energy may be created using a method similar to combined cycle gas power plants by using biogas from various biomass. Rubbish thermal power plants run on methane gas, a combustible biogas produced by urban trash, garbage decaying, and anaerobic fermentation (exchange of oxygen-free environment-oxygen-free breathing-fermentation). As a result, it is conceivable to employ urban garbage to generate electricity while also addressing the issue of waste storage.

2.3.4.1 Biomass Energy World Outlook

Table 2.7 [59] shows the top ten nation leading in the generation of energy from biomass in 2020.

Table 2.7 Installed Capacity from Biomass in Top 10 Countries in 2020.

	Countries	Installed Capacity (Mw)
1	China	18,686.892
2	Brazil	15,650.017
3	USA	11,980.100
4	India	10,532.245
5	Germany	10,366.500
6	UK	7,243.009
7	Sweden	5,298.500
8	Thailand	4,389.110
9	Italy	3,554.148
10	Republic of Korea	2,726.311

2.3.5 Hydroelectric Power

Hydroelectric power plants are constructed in dam lakes formed by damming rivers to provide drinking, usage, or industrial water. The dams elevate the water level. The turbine generates motion energy by rotating with the potential energy of the water, which is subsequently turned into electricity. Electricity is generated by the generators attached to the spinning turbine.

The major components of a hydroelectric power plant include dams, penstock pipelines, hydraulic turbines, generators, transformers, and ancillary equipment that manage water flow and electrical energy delivery. Penstock pipes are massive tubes or tunnels that transport water from turbines to turbine blades. Turbines are machines that convert the hydraulic energy of flowing water into mechanical energy. Transformers transform the electrical energy produced by generators into a high voltage that can be delivered across long distances.

Hydro power installed capacity is around 1,300 Gwe in the world in 2020 by the International Energy Agency (IEA). Turkey has 31 Gwe installed hydropower capacity as of 2020 by EMRA records.

2.3.6 Wave Energy

It's the energy generated by the cylinders created by connecting a 1/7 prototype wave energy converter to cylinder-reinforced filament glass.

When it comes to wave energy, the energy transfers that occur as a result of tide should not be understood. Although the source of this energy is a sea movement, astronomical factors have a role in its occurrence. Since the beginning of the energy crisis in 1973, research, development, and technological structure have been focused in order to enhance the use of renewable energy sources [23].

Wave energy has the potential to become one of the most significant clean and renewable energy sources in the future, assisting in the removal of the detrimental effects of fossil fuels from the atmosphere. Furthermore, it has no negative environmental impact and, in addition to the amenities to be built, it offers substantial advantages in terms of being used as a tourism facility, industrial, or residential area.

2.3.7 Tidal Energy

The rapid movement of water volume induced by tidal movement is known as tidal flow. In tidal current technology, the kinetic energy in the tidal current induced by tide rise and fall is utilized to create electricity. Tidal flow is more common in shallow seas with natural tunnels that lead water to flow more quickly.

Although there are significant distinctions, tidal current technology is fairly similar to wind energy technology. Tidal currents move at a slow pace (2-3 m/s). However, depending on the local geography, this speed may vary. Current rises, particularly in the straits between the islands or between the island and the mainland [24].

Tidal flow turbines provide a number of distinct advantages. These;

- They have a minor influence on the environment.
- Energy consumption is particularly high in gigawatt-scale projects.
- Because of tidal energy, current energy can be precisely measured.
- Tidal currents have a high capacity factor, typically in the 40-60% range.
- Flowing water has a far higher power density than other renewable energy.
- This low-cost technology opens up new opportunities for industries.

2.4 Hydrogen Energy Systems

Hydrogen can be produced from any primary energy sources and that is why it is not the primary energy source.

Hydrogen is the most basic and abundant element in the universe, with the largest energy content per unit weight of any known fuel. Hydrogen is considered as the most important source of clean energy since it does not absorb gases such as carbon dioxide from other fuels during combustion and produces only pure water as waste. The following are some techniques for producing hydrogen:

- Method of steam-methane regeneration,
- Electrolysis method,
- Thermo-chemical decomposition method,
- Steam electrolysis method,
- Photo-electrochemical method,
- Biomass gasification and pyrolysis.

Because of technological advancements, hydrogen energy is now utilized in a variety of areas. The most notable of these is because it can be stored in metal composites, making it simpler to store than electricity, and it is employed in transportation. These cars, which emit only water vapor, have reduced environmental impact by using hydrogen fuel cells. Its chemical wattage is more than that of any other known chemical substance, hence it is employed in the fuels of space shuttle rockets.

Aside from that, because of its ability to be quickly turned into energy, it is increasingly being employed in mobile phones and laptop computers.

The advancement of hydrogen technology has demonstrated that hydrogen is an incredibly significant energy carrier in raising living standards and guaranteeing global stability. Accelerating the transition to a hydrogen economy is critical for ensuring long-term growth based on hydrogen and permanently resolving environmental issues [22].

3. MICROGRID SYSTEMS

Microgrid (MG) pioneers include the Consortium for Electric Reliability and Technological Solutions (CERTS) and the EU Commission on Microgrid. "Microgrids are a set of micro sources that act like a centrally-controlled power production system providing heat and power," according to CERTS.

Microgrids are "electronically constructed to improve power dependability and power supply continuity"[3]. Figure 3.1 depicts CERTS's concept of MG.

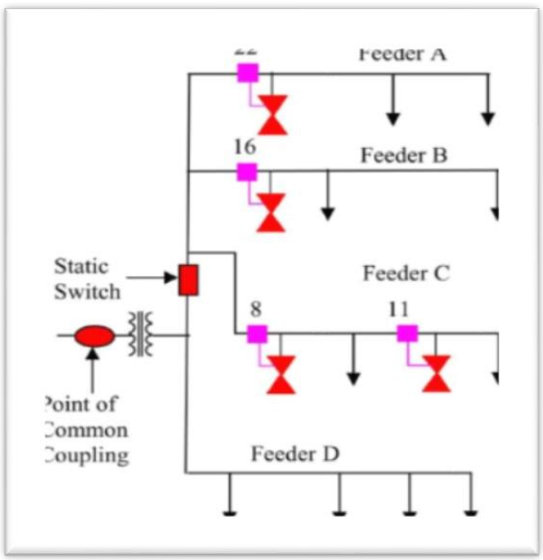


Figure 3.1 Microgrid structure.

Microgrids are LV power-distribution systems that combine distributed energy resources (such as PV, microturbines, fuel cells, and so on), storage devices such as batteries, flywheels, and flexible loads, according to particular research efforts performed by the European Union [25,26]. Figure 3.2 shows a representation of MG based on European Union research programs.

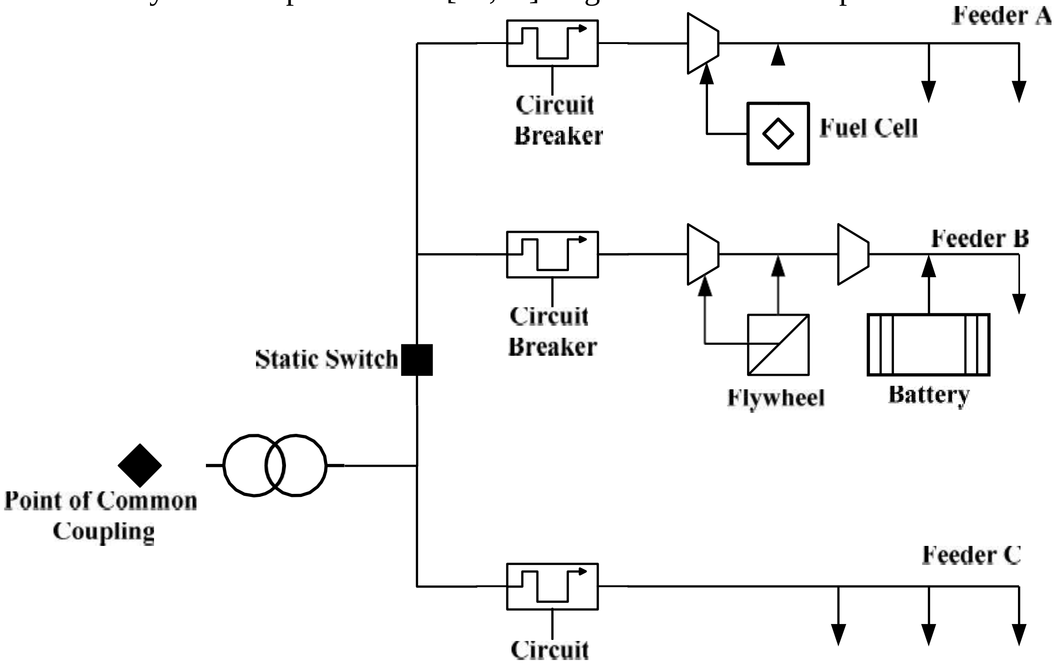


Figure 3.2 A vision of MG by EU projects.

Microgrids should be considered both a supply-side integration platform for microgeneration equipment and a factor in load control and power-shortage units of a local distribution grid. The Microgrid idea focuses on delivering local electricity to local loads. As a result, aggregation models that do not include generator installations, such as virtually-operated power plants, cannot be deemed microgrids. MGs should have resources for both supply and demand. Its average LV microgeneration capacity is in the MW range [27, 28].

3.1 Types Of Mıcrogrıd

The first type of MG is an island microgrid, which is made up of DGs and DSs and delivers electricity to small-scale users or communities. Because of its remoteness, this has been separated from the power grid, preventing access to the main system (Table 3.1).

LV microgrids, on the other hand, meet the electrical demands of a small scale, such as a commercial farm or a farmhouse in a remote place. It operates in parallel with the grid system. As a consequence, if there are any distribution network issues, the DG or DS units can meet the customer's power demand in the island mode.

Table 3.1 Microgrid types [29].

Type of Microgrid	Example
Separated island microgrid	One village, city or island outside utility grid
Low voltage customer microgrid	One household that includes DER
Low voltage microgrid	Low voltage network that can include many DER units and customers
Medium voltage feeder microgrid	Output of one high voltage/medium voltage substation

The third kind of LV microgrid delivers services to a large number of LV clients, and power generation is based on a variety of small-scale DGs such as solar panels, wind turbines, or microturbines. LV microgrids can have a restricted or large range since, on the one hand, they offer power to a few consumption sites and, on the other hand, they can give electricity to an entire low-voltage network working with the assistance of either an MV or an LV transformation system.

The fourth form of MG is LV-microgrid, which is subdivided into MV-microgrid with high-capacity DG units. These DG units will then be linked to the main high voltage (HV)/ medium voltage(MV) distribution network [29].

The above mentioned four options are represented in the Figure 3.3.

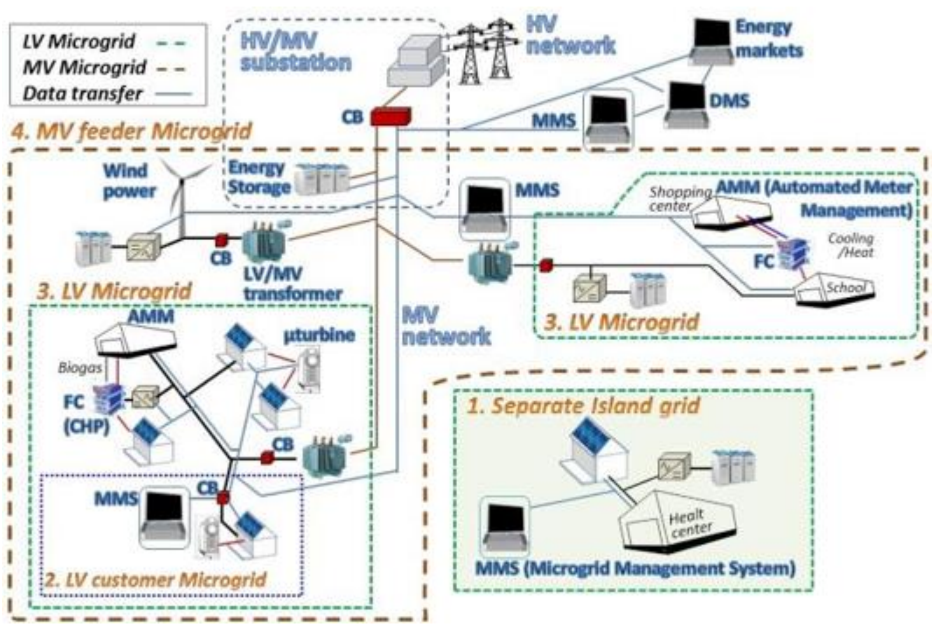


Figure 3.3 Types of microgrids.

1. Separated island microgrid	2. Low voltage customer microgrid
3. Low voltage microgrid	4. Medium voltage microgrid [29]

All of these microgrids show that microgrids may come in a variety of sizes. The capacity of the LV customer-side grid may be less than 10 kW. Many DERs ranging from 10 to 100 kW are used in island and low-voltage microgrids, and their installed capacity is less than MW in real time.

With growing MG size, i.e. the number of distributed generating and storage units, balancing capabilities and controllability improve, and hence system resilience and stability improve [30].

The voltage of a microgrid is proportional to its size. Customers' LV grids are connected to the LV central grid, whereas LV micros, which contain several DERs or customers, are connected to the MV-central grid [31].

The way power is transported and distributed through microgrids allows for microgrid setup (Figure 3.4). It has higher frequency (HFAC) AC MGs or DC MGs, hybrid DC/AC MGs, and MGs in the line frequency AC category (LFAC).

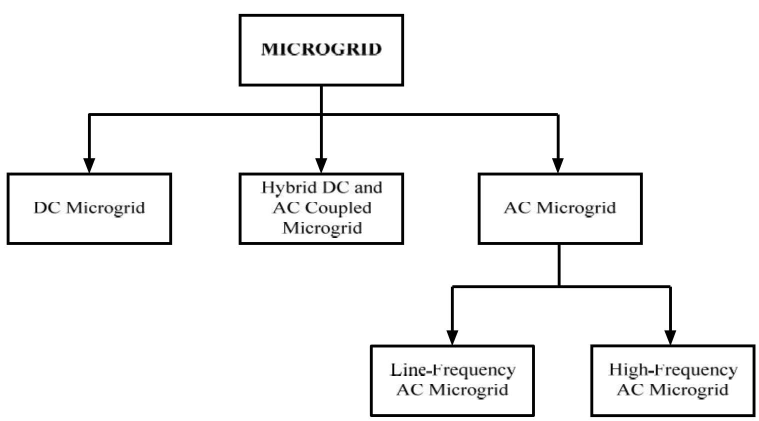


Figure 3.4 Classification of microgrids based on power type

3.2 AC Microgrid

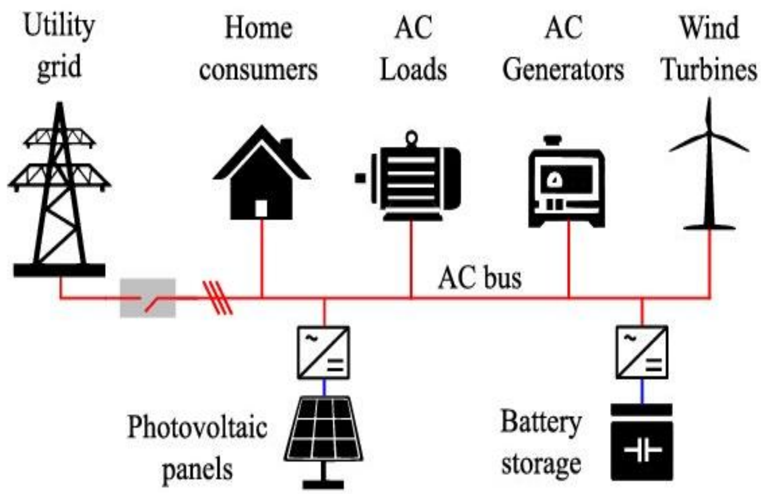


Figure 3.5 AC Microgrid architecture

3.2.1 High Frequency Alternative Current (HFAC) Microgrid

A single-phase 400 Hz distributed network system is employed mostly in the military and aviation systems [33]. Microgrid systems have been in use for military and aerospace systems for quite some time. When frequency is raised, the size and weight of power-electronics equipment can be lowered.

Because longer lengths increase power losses, HFACs are mostly used in limited regions. As a result, this notion is only applicable to localized power generation systems [34]. [35] provides an example of an HFAC microgrid.

Normally, a unified power quality conditioner is implemented to reduce voltage distortions in nonlinear power loads. The ultra-performance liquid chromatography (UPLC) is responsible for connecting the HFAC link to the main grid and controlling power flows from and to the microgrid.

Two flexible alternating current transmission system (FACTS) systems, obviously, necessitate control-mechanism components that govern power flow through microgrid, allowing a microgrid to function at very high frequencies ranging from 400 to 500Hz. Power loss and voltage droop in HFACs, on the other hand, increase with frequency and line length. As a result, while sizing any HFAC microgrid, these issues must be considered [34,35].

3.2.2 low frequency alternative current (LFAC) Microgrid

Microgrid LFAC has piqued the curiosity of researchers. A wide variety of LFAC microgrid options have been studied in the literature [36, 37, 38].

Distributed energy sources (DERs) in LFAC microgrids are linked to MG through a shared bus. In this situation, the microsource's DC current is converted to 50 Hz AC via an inverter and sent to the consumer [36].

3.2.3 DC Microgrid

DC microgrids are widely utilized in telecommunications [39], electric cars [40], and naval energy generating [41].

Low-voltage direct current (LVDC) microgrids have recently emerged as a feasible alternative due to their capacity to manage large electronic loads in official and commercial buildings, for example, LVDC microgrids ensure commercial-purpose power production for extremely sensitive power loads [42]. Figure 3.6 depicts the overall construction of a microgrid.

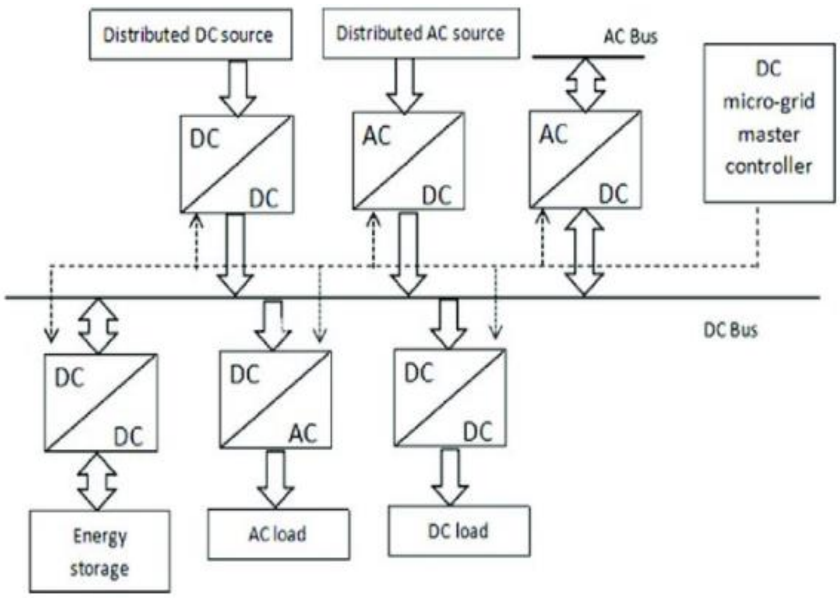


Figure 3.6 A general structure of a DC microgrid [43].

3.2.4 Hybrid Microgrid

[33,44] show the core microgrid system design with DC or AC connections.

It describes strategies for incorporating a DER-variety into an existing distribution infrastructure. A DC-/AC-coupled hybrid microgrid requires DC to connect distributed energy storage devices linked to AC-DC converters and DC equipment, such as PVs linked to DC-DC boosting-converters and low-scale turbines that run on gas or wind.

Power converters are typically used to achieve decoupled management of microgrid DC or AC components [44].

DC/AC-coupled hybrid-microgrids are a concept that gives a simpler way to connect DERs in order to get better protection and reliable operations; nevertheless, additional research is required.

3.3 Examples of µG

Examples of µG's with parallels and distinctions from several countries, including China, Greece, India, Spain, and Japan, are provided in this section:

China

The largest µG in Zhangbei-China with 160 MW, as illustrated in Fig. 1.2 below, includes a wind turbine of 100MW, a PV cell of 40MW, a main grid connection, and a battery energystorage system of 20MW.

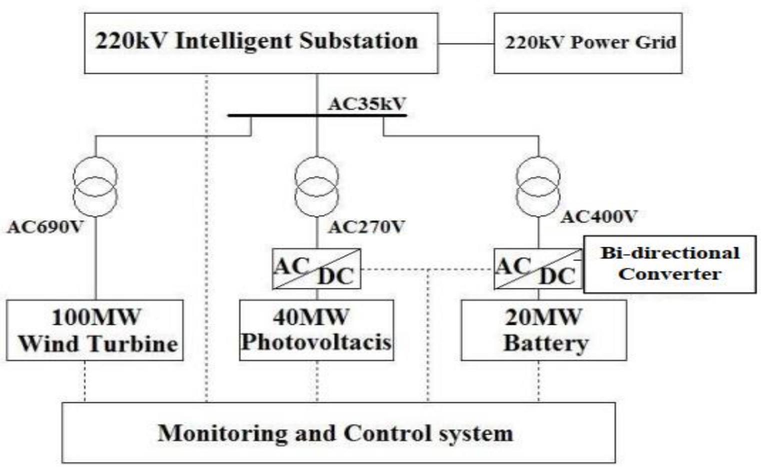


Figure 3.7 Micro-Grid in Zhangbei-china [45].

3.3.1 Greece

In Greece, the Kythnos, which consists of a diesel generator, a PV cell, and a battery bank, is located on an island in the Aegean Sea's Cyclades Archipelago [46].

This µG can supply the demand power for 12 houses on the island. If necessary, the battery power can be balanced between loads and micro sources. Figure 1.3 shows the µG of Kythnos site.

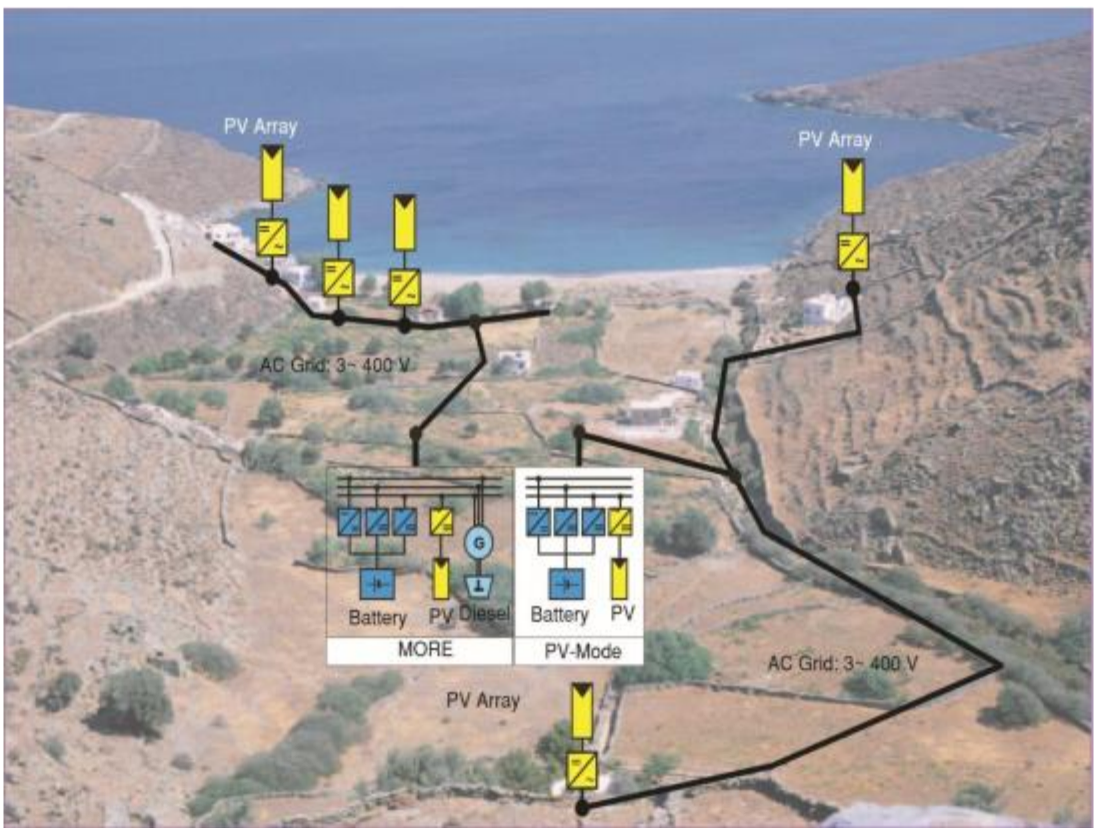


Figure 3.8 µG of Kythnos [46].

3.3.2 Spain

The Catalonia Institute for Energy Research (IRECG)'s μG is located in Barcelona, Spain. It has a capacity of 200kW and is presented in Figure 1.4 as a single line diagram.

The IREC's μG components include the emulated system, the genuine system, the semi-emulated system, and others, each with their rated values and description, as cited in [47]. On a single line diagram of IREC's μG, the first, second, and third units represent wind power generation, storage, and a consumer's node, respectively. The sole distinction between this μG and others is that the plug-in electric vehicle (PEV) might provide electricity to the IREC's μG or vice versa.

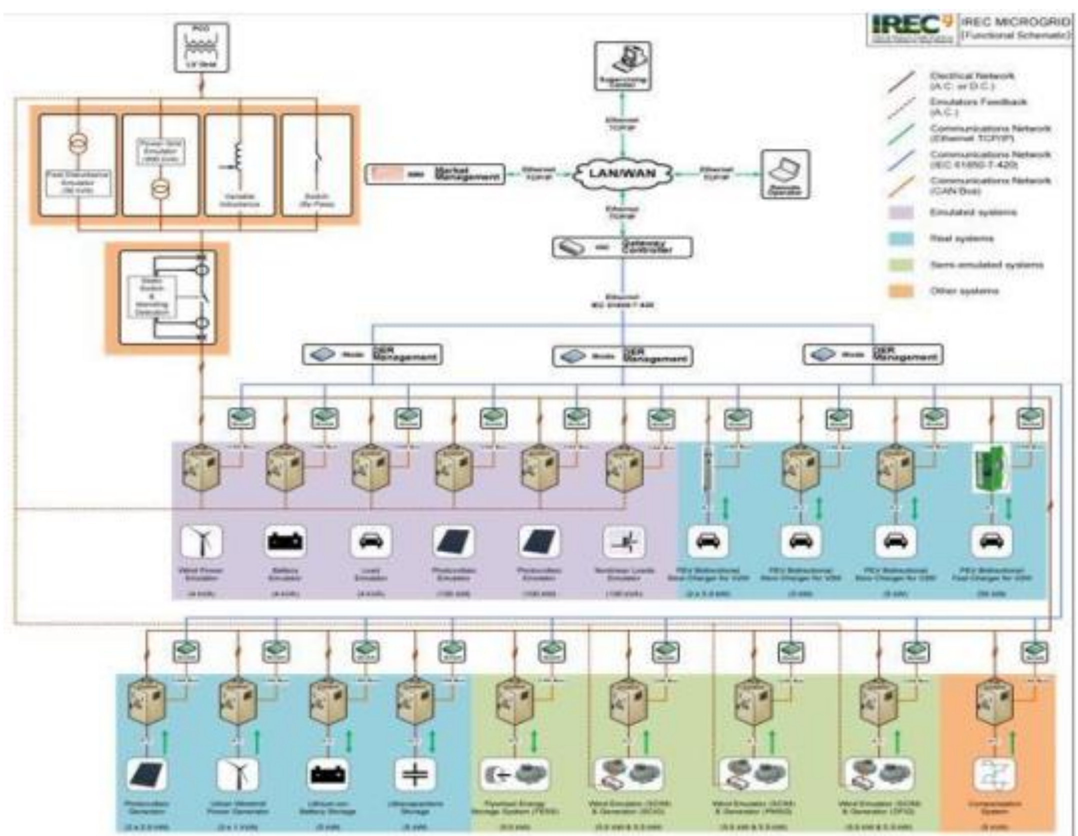


Figure 3.9 Single Line Diagram of IREC [47].

3.3.3 Japan

In [48], an islanded µG was built, which included a diesel generator, a PV cell, a wind turbine, and a storage energy system that had both lead acid and lithium batteries. The island µG is located in six towns of Kyushu, Japan: Kuroshima, Takeshima, Nakanoshima, Suwanosejima, Kodakarajima, and Takarajima. PV panels and diesel generators are installed on each of this island.

Because of the generator inertia issue, they are experiencing swings in both the PV and loads sites. A µG must be considered in order to answer these problems. A 10kW wind turbine and a 60kW PV system are combined with a 240kW power station to produce a µG for Kuroshima Island, as demonstrated below.

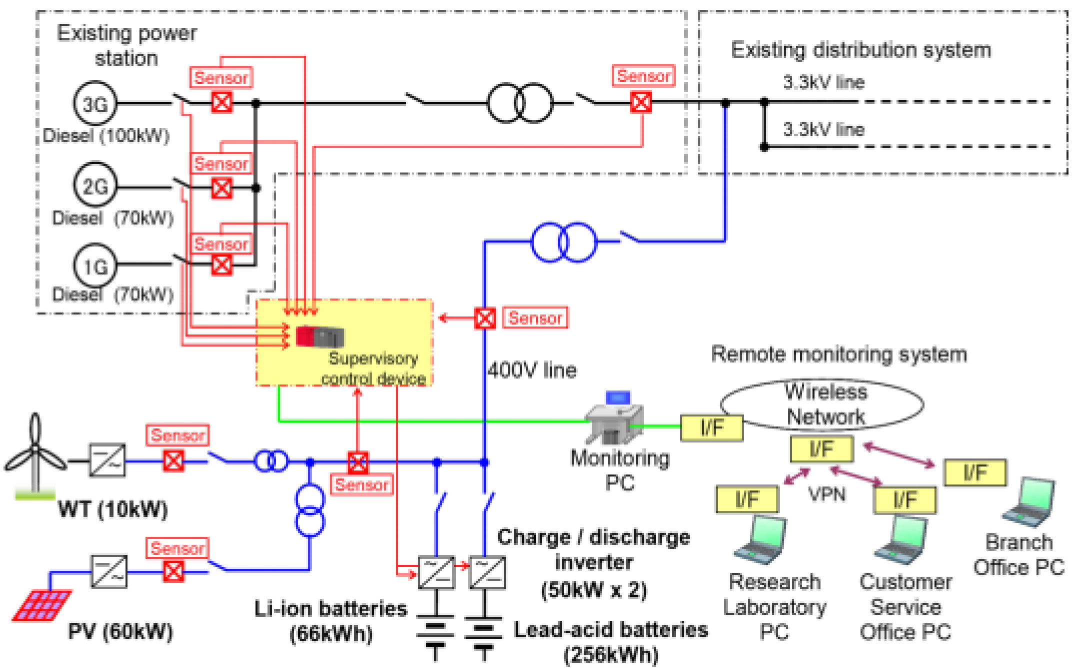


Figure 3.10 Installed µG of kuroshima island [48].

3.3.4 Maldives-India's Ocean

In a remote location of the Republic of Maldivian, India's the islands of Uligam, Raimandhoo, and Kondey have a three-µgrid system with a 24×1.8kW wind turbine, a 30kW diesel generator, and 2.5kW PV cells on each island. However, only Uligam Island has been examined in this case. They were solely using a diesel generator as a source of electricity back then. They have decided to construct a µG in order to minimize diesel prices and supply reliable power to their customers.

A diesel generator's high demand is charged at approximately 9L/h for each 30kW. As a result, they offered a µG with the aforementioned µsources, as well as the existence of the diesel generator, as illustrated below.

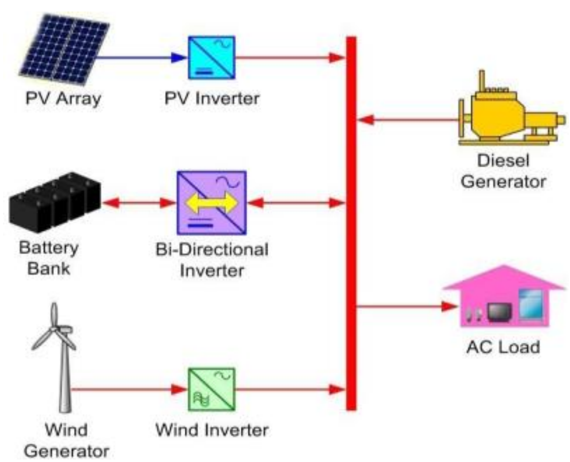


Figure 3.11 Single Line Diagram of Uligam Island [49].

3.3.5 Similarities and Differences

The commonalities across countries' µG are chosen based on their components, which are bi-directional inverted, monitoring and control center, photovoltaic cells, batteries, and loads. The differences were also chosen based on the diesel generator's connection to the main grid and the PEV.

The only similarities across the countries' µG are photovoltaics, batteries, and loads, while the contrasts are clearly displayed in the table above with PEV, wind turbine, and diesel generator connected to the main grid.

Table 3.2 Comparison of the components

Countries	Components
China	battery, photovoltaic cell, load, main-grid and wind-turbine
Spain	battery and capacitance, photovoltaic cell, load, PEV and wind-turbine
Greece	battery, photovoltaic cell, load, and diesel generator
Maldives-India's Ocean	battery, photovoltaic cell, load, wind-turbine and diesel generator
Japan	battery, photovoltaic cell, load, and wind-turbine

3.4 Operation Modes of Microgrid

MGs perform the following functions:

• isolated or island function mode, if the MG is self-contained;

• grid-connected mode, if the MG is linked to the main grid.

The importance of Microgrids, the availability of essential energy sources, and the cost of those sources all impact local power generating options on the island. Consider the limitations of MV or LV transformers, as well as low voltage network congestions.

Microgrid rapidly changes to a self-sufficient islanding operation in the case of an MV or HV system failure. A seamless transition from networked to islanding generation is important to assuring continuous power supply.

In this situation, MCs and LCs work independently to make effective use of local resources while maintaining system operations in islanded conditions.

When MGs are partially or entirely connected to the grid, the excess power generated in the MG can be transferred to the main grid, providing supplementary services. Within the distribution system design and loads-collection, MG may have radial feeding devices (A, B, and C) (Figure 3.5). Static switches link the radial-type MG to the common coupling point.

Point of common coupling (PCC)s are primary transformers that divide the main grid from the MGs. Circuit breakers and micro-source controllers are installed in each feeder. Local critical loads are shifted to local generating resources, whereas non-critical loads have no local generation. The static switch aids in the islanding of the MG during interruptions or maintenance [50].

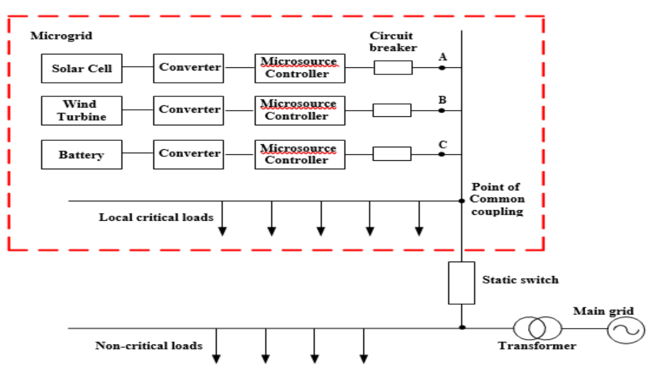


Figure 3.12 Schematic microgrid diagram.

4. THE STUDY METHODOLOGY

In this study, Büyükada Island is selected to be a project site because it is the biggest one among the other islands and till nowadays it does not have a serious renewable energy project. From the concept of decarbonization, it is recommended to create a microgrid that can produce clean energy to the island from renewable energy sources instead of the current method which is supplying the island with cables under the sea. Hence, the figure 4.1 shows the map of Büyükada.

As can be shown in figure 4.1, the places with population and the places without population, so the microgrid can be in the places where there is no much of population, almost in the middle of the island.

Figure 4.1 General view for Büyükada (island)

After selecting the map and downloading the solar and wind resources from Homer Pro, the load profile is downloaded from the Homer Pro library which is a similar place conditions in USA.

And all the other components like the solar PV panel, wind turbine, generators, battery systems and the system converter are all selected to meet the load chosen.

All these components of the microgrid are discussed in details in the next chapter following with the results out of this microgrid.

4.1 Overview of Büyükada (Island)

There are a total of 9 islands near the Anatolian part of Istanbul. 5 of them are operational for people to visit, live and explore. Büyükada is the largest of the Princes' Islands in the Sea of Marmara, near Istanbul, with an area of about 2 square miles (5 square kilometers). It is officially a neighborhood in the Adalar (Islands) district of Istanbul Province, Turkey. Currently energy is supplied from the Asian part to fulfill the energy requirements. Adalar district is divided into five districts, as shown in Figure 4.2: Maden, Nizam, Büyükada, Heybeliada, Knalada, and Burgazada. There are also

Figure 4.2 General View of Adalar District.

Democracy and Freedom Islands, as well as the Sivriada islands, which have yet to be populated. The islands have a surface area of around 16 km2, a population of 15,238 people, and the population has expanded since the spring months, reaching over 72,000 people. Because Adalar is a tourist destination, its population is estimated to be over 140,000 people, with daily visits.

Büyükada is the fourth largest and most populated island near Istanbul among the other islands and the energy is being supplied under the sea from the city. Related to this, it is possible to use micro grid systems on this island with the aim to apply renewable energy sources to Büyükada. Initial studies showed the potential of renewable sources on the island. Solar, Wind, and Biomass proved to have enough potential to handle the energy requirements. There are 8-9 sites in Asian Istanbul (Kartal, Maltepe, Bostanci and others) that provides electricity to the Islands as shown in figure 4.3 below. 10.5kV is the transmission level and transmission is done under the sea in the form of ring topology. After all the losses, voltage level reaching the islands is 10.2kV-10.3kV. Transmission and Distribution is done in AC so the distribution voltage level is 230V-400V which consists of 23 distribution stations are on 6 islands.

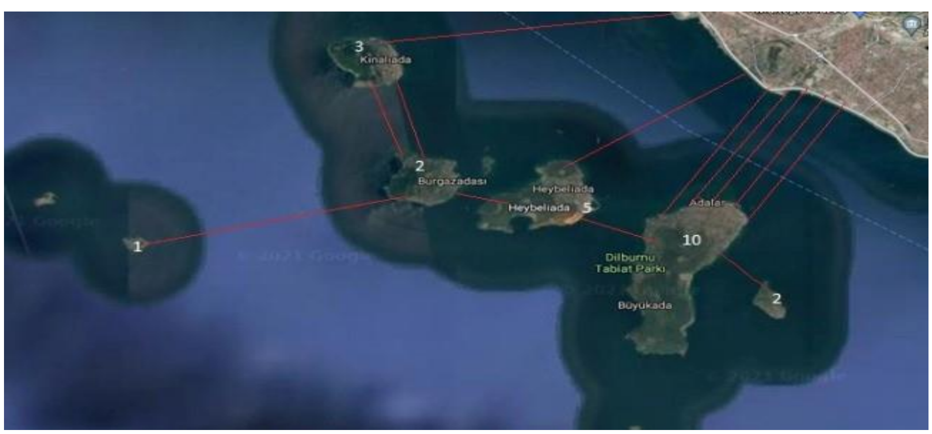


Figure 4.3 Adalar Map Showing the ring topology and the substation connections.

The numbers 1,2,3,5 and 10 represents the number of substations on each island.

Figure 4.4 shows the daily electrical load distribution of the Adalar district based on the spring season. As can be seen, between 18:00 and 20:00 in the evening, the electrical load rises to 60,000 kW, and between 06:00 and 12:00 in the morning, the electrical load is around 20,000 kW. Between 00:00 and 03:00 at night, the electrical load is around 5000 kW.

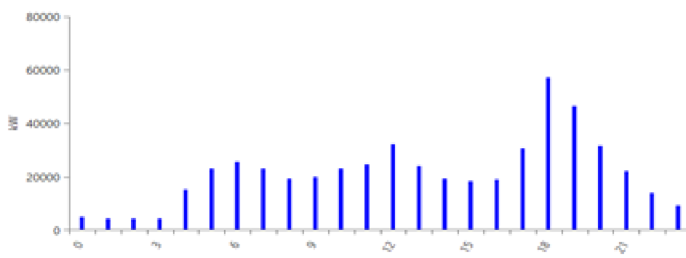


Figure 4.4 Daily Electric Load Profile of Adalar District.

4.2 Using Software: Homer Pro

The system design was performed by Homer Pro software in the study.

HOMER Energy's HOMER Pro® microgrid software is the global standard for optimizing microgrid design across all industries, from village electricity and island utilities to grid-connected campuses and military locations. HOMER Pro, also known as HOMER (Hybrid Optimization of Multiple Electric Renewables), makes it easier to evaluate designs for both off-grid and grid-connected power systems. When designing a power system, you must make several considerations concerning the system's setup, such as:

- What are the finest components for this system?
- What is the most efficient number and size of each component?

These selections are complex due to the enormous number of technological possibilities, pricing variations, and the availability of energy supplies. The optimization and sensitivity analysis techniques in HOMER make it easy to analyze the numerous system configurations.

4.3 Studying with Homer-Pro

HOMER simulates energy systems, displays system configurations that are cost-effective, and does sensitivity analyses.

4.3.1 The Simulation

HOMER simulates system functioning by performing energy balance calculations at each time step (interval) throughout the year. HOMER estimates the flow of energy to and from each component of the system for each time step by comparing the electric and thermal demand in that time step to the energy that the system can deliver in that time step. HOMER selects how to operate the generators and whether to charge or discharge the batteries in each time step for systems that involve batteries or fuel-powered generators.

HOMER calculates the energy balance for each system configuration you choose to investigate. It then analyzes if a design is practical (that is, whether it can fulfill the specified electric demand) and calculates the cost of installing and operating the system during the project's lifetime. Capital, replacement, operation and maintenance, fuel, and interest are all factored into the system cost estimates.

4.3.2 The Optimization

There are two optimization algorithms in HOMER Pro. The original grid search technique replicates all of the Search Space's conceivable system configurations. To find the most cost-effective system, the new HOMER Optimizer employs a unique derivative-free method. HOMER then shows a list of configurations ordered by net present cost (also known as life-cycle cost) for you to evaluate system design possibilities.

4.3.3 The Sensitivity Analysis

When sensitivity variables are specified as inputs, HOMER repeats the optimization procedure for each sensitivity variable. For example, if you give wind speed as a sensitivity variable, HOMER will simulate system configurations for the specified range of wind speeds.

4.3.4 Solving Problems With Homer Pro

HOMER makes it easier to construct distributed generation (DG) systems, both on and off the grid. The optimization and sensitivity analysis algorithms in HOMER enable us to determine the economic and technical viability of a wide range of technology solutions while accounting for differences in technology costs and energy resource availability.

Working well with HOMER necessitates a grasp of its three primary capabilities: simulation, optimization, and sensitivity analysis, as well as how they interact with one another [60].

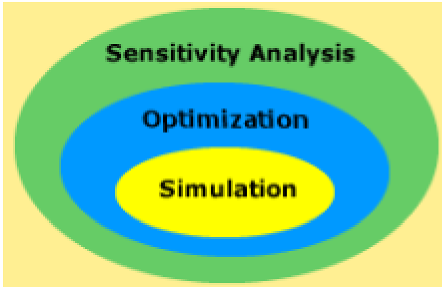


Figure 4.5 Types of Algorithms Used By Homer Pro

5. DESIGNING THE MICROGRID SYSTEM CONFIGURATıON

In this study it is applied solar PV, wind turbine, energy storage, biogas generator along with a diesel generator because it is more reliable in this way when all these components work together and all the details of this study can be found in the following section.

5.1 The Concept of the Design

The next Figure 5.1 will show the schematic studied. Which consists of the load, wind turbine, PV systems, battery systems, auto-size genset with biogas genset.

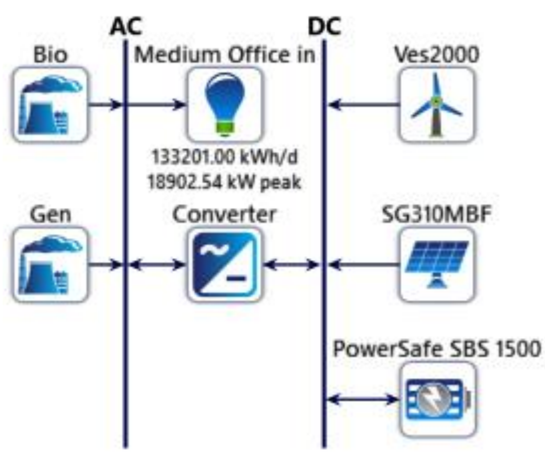


Figure 5.1 The schematic of the system studied.

5.2 Electric Load

Figure 5.2 The electric load profile characteristics.

After choosing the map of the Büyükada on Homer Pro, there is the electric load profile per year for every hour per day to be selected. Since this type of data can not be taken from ayedas (the electrical company in Istanbul) thus, similar data and location is taken from the library of Homer Pro at a place in USA which is a small office in Walla Walla city. The scaled annual energy for Büyükada -Maden Mah is 133201 (KWh/day). The Figure 5.2 shows the daily, seasonal and yearly profile with the scaled annual average.

5.3 The Wind Energy Potential of Büyükada Island

Wind energy is often regarded as one of the most important renewable energy sources [61,62]. There are two types of power plants in the globe, as shown in Figure 5.3: onshore and offshore. The (WPP) type was introduced. The percentage of offshore wind farms in total installed capacity has nearly quadrupled in the previous decade.

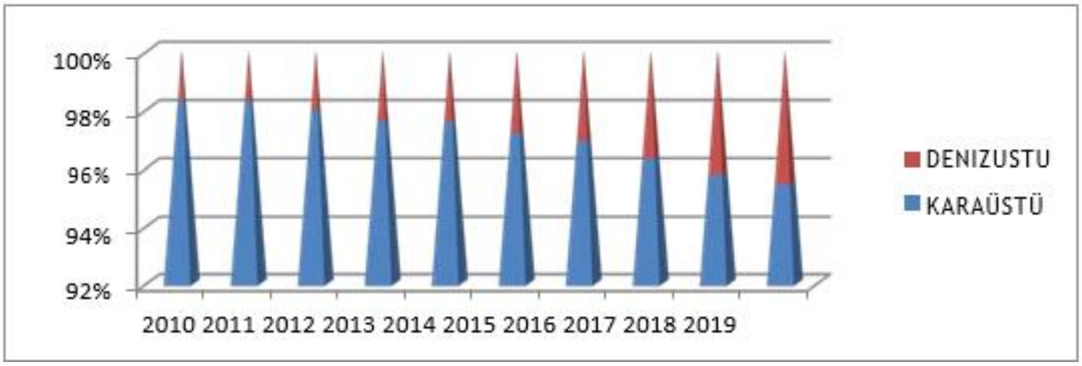


Figure 5.3 In terms of installed power, the distribution of offshore and onshore wind farms throughout the world [63].

Wind energy has also increased significantly in Turkey in tandem with global advances. In the last 10 years, investments in renewable energy resources have gained traction in Turkey. Figure 5.4 shows that by 2020, nearly half of installed electricity will be made up of power plants connected to renewable energy sources.

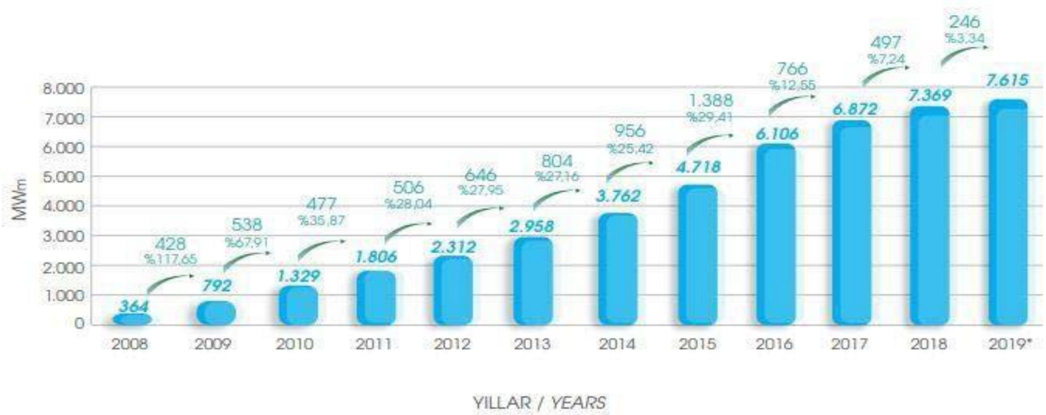


Figure 5.4 Wind Farm Powers Established in Turkey Between 2008-2019 [64].

Table 1 displays the 2019 power usage values for the Islands. The Büyükada area has the highest consumption. It is followed by Heybeliada, Knalada, and Burgazada, in that order. In 2019, the islands' power usage is estimated to be at 171 GWh [65].

Table 5.1 Total Electricity Consumption in Adalar District in 2019 by Neighborhood

year	District	Neighborhood	Population	Population rate	Annual Total Electricity Consumption (kWh/day)	Annual Total Electricity Consumption (kWh/year)
2019	Adalar	Maden Mah,	4.330	28,42%	133.201	**48.618.492**
2019	Adalar	Heybeliada Mah,	4.253	27,91%	130.833	**47.753.914**
2019	Adalar	Nizam Mah,	3.470	22,77%	106.746	**38.962.163**
2019	Adalar	Kınalıada Mah,	1.758	11,54%	54.080	**19.739.332**
2019	Adalar	Burgazada Mah,	1.427	9,36%	43.898	**16.022.769**
2019	**Adalar**	**Whole Districts**	**15.238**	**100,00%**	**468.758**	**171.096.670**

Büyükada Meteorology Observation Station (altitude: 165m latitude: 40.85 longitude: 29.11) Adalar Observation Station provided average wind speed (m/s) measurements and wind directions (altitude: 2m latitude:40.93 longitude:28.94). These figures are for the years 2017-2019 [66].

The following factors must be considered when designing an onshore WPP power plant: air density (kg/m3), wind speed value (m/s) for many years, wind direction, wind field roughness surface, wind distribution factor (k), turbine body height, rotor diameter, distance between turbines, projection losses, transformer center distance, land ownership structure, topographic structure, land slope, and elevation [67].

The main factors to be considered while designing an offshore WPP power plant are; Apart from the factors that should be considered on land, sea water depth, distance to the shore, and sea traffic routes [68,69].

5.3.1 The Wind Power Plant Design

In the scope of the design, the following points to be considered when choosing a wind farm location;

1. Under Turkish law, a maximum safety distance of 300 m shall be maintained between the wind farm and the settlement [70]. The main objective of this distance is to reduce the amount of noise produced by the wind turbine.
2. The closeness of wind turbines to the transformer center gives a major economic benefit.
3. There shall be no constraints prohibiting the development of the WPP on the WPP site's property, such as natural protected regions or cultural areas.

Figure 5.5 shows the land slope value. Areas in white indicate the slope of 0, areas in yellow indicate between 5% and 15%, and areas in orange and dark red indicate between 15% and 25% of the slope.

1. It is not recommended to establish wind farms on lands with a slope of more than 5 percent.

Taking everything into account, the area highlighted in yellow to the south of Büyükada is ideal for turbine installation. Because of the limited space available, only one turbine can be installed.

Other places, such as Heybeliada, Knalada, Burgazada, and Sedefadas, lack sufficient area for wind turbine installation.

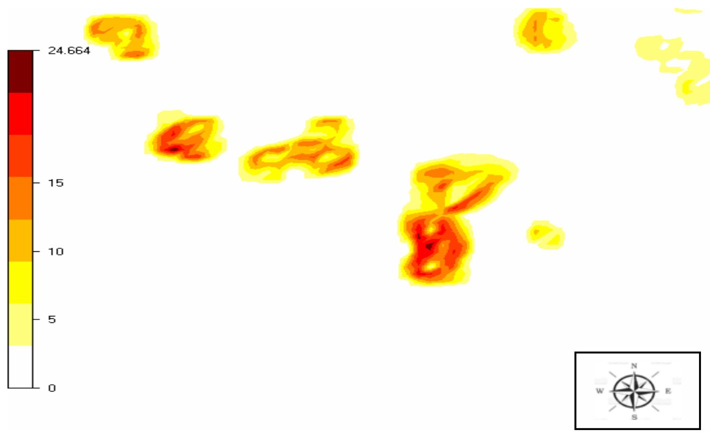


Figure 5.5 Land Slope Value.

The frequency graph of wind speed and the Weibull distribution are shown in Figure 5.6, based on data from the Büyükada observation station. The most extreme wind speed dispersion may be found at 4-6 m/s. Between 2017 and 2019, observations taken at the Büyükada Meteorology Observation Station yielded an average wind speed of 5.27 m/s at 12 m height [71].

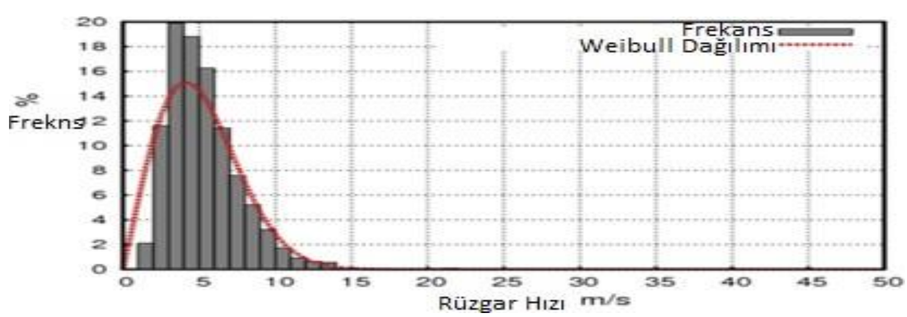


Figure 5.6 Büyükada Meteorology Observation Station Frequency Distribution Table.

In terms of wind speeds, yellow denotes 4-8 m/s, orange 8-12 m/s, red 12-16 m/s, and dark red greater than 16 m/s in Figure 5.7. symbolizes a fast moving object.

In terms of wind speed, the northeast is responsible for around 30% of the wind.

The turbines are oriented toward the prevailing wind direction in this design. (northeast).

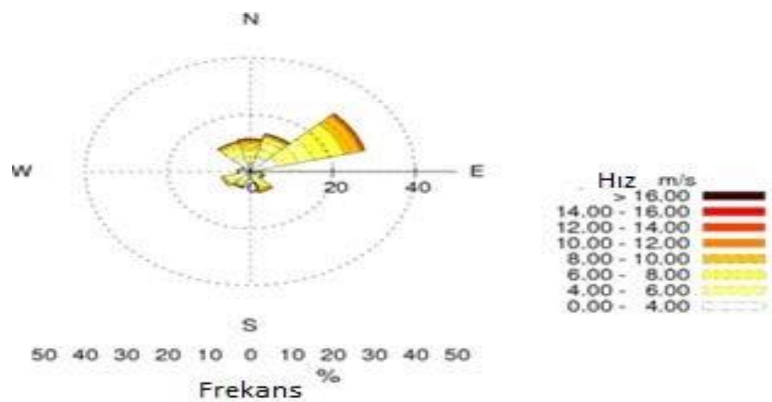


Figure 5.7 Distribution of Wind Direction and Intensity at Büyükada Meteorology observation Station.

The wind speed dispersion according to the turbine body height is seen in Figure 5.8. (119 m). The measurement station is represented by the circle, while the wind turbine is represented by the triangles. The wind speed in white regions ranges from 1.5 to 4 m/s. The wind speed in the yellow areas is roughly 4 m/s. Wind speeds range from 4.2 to 5 m/s in regions ranging from yellow to dark red.

Wind turbines should be installed where there are strong wind speeds and regions that are ideal for the slope of the land. The layout of the wind turbine should be verified, as shown in Figure 5.5. Only one turbine may be placed on the land in this case, and the most appropriate micro-positioning analysis was carried out based on the wind speed distribution.

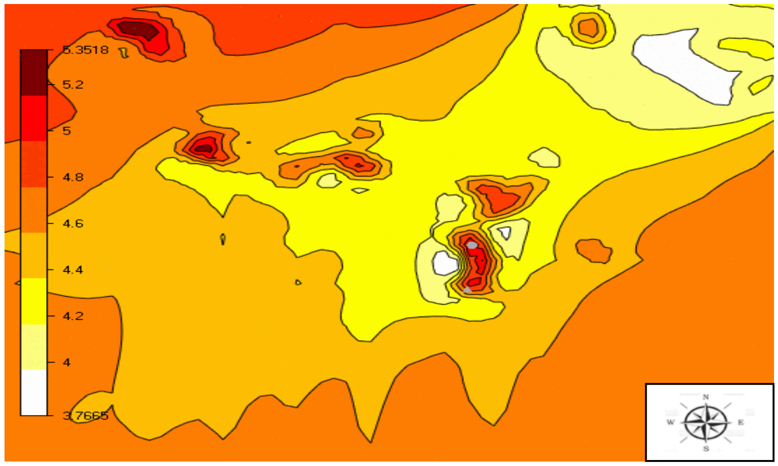


Figure 5.8 The wind speed distribution according to the turbine body height (119 m).

The IEC Wind Turbine classification is a crucial factor to consider when choosing a wind turbine. Based on the yearly average wind speed (max), there are four classifications:

- IEC 1 (High Wind) 10 m/s,
- IEC 2 (Middle Wind) 8.5 m/s,
- IEC 3 (Low Wind) 7.5 m/s
- IEC 4 (Very Low Wind) 6 m/s [72]

In regions with low wind speed, turbines with IEC 4 type classification are used, so IEC 4 type wind turbines should be selected for this region.

The table 5.2 shows 3 types of turbines. The capacity factors of these 3 types of turbines were compared.

As the rotor diameter grows, the yearly power generation and capacity factor rise linearly.

Therefore, it has been determined that the most suitable turbine type for the region is "VESTAS 2.0 MW V120". But in Homer Pro there is only the VESTAS 2.0 MW V110 so this type has been chosen instead.

Table 5.2 Analysis of Electricity Production and Capacity Factors by Turbine Types

Turbine Type	**V90**	**V110**	**V120**
Power (MW)	2	2	**2**
Rotor Diameter (D)	90	110	**120**
With Electricity Generation Projection Losses (GWh/y)	2,47	3,76	**4,2**
Capacity Factor (%)	**14,09**	**21,4**	**23,9**

5.4 Autosize Genset

An Auto genset has been chosen which can automatically sizes itself to meet the the load. The capacity of the generator will be the smallest that will produce no capacity shortage in all sensitivity cases and future years (if using multi-years analysis). İt also adjusts its fuel curve to match its size.

properties of this generator:

- Fuel: Diesel
- Fuel curve intercept: 308 L/hr
- Fuel curve slope: 0.236 L/hr/KW

Emissions:

- CO (g/L fuel): 16.5

- Unburned HC (g/L fuel): 0.72
- Particulates (g/L fuel): 0.1
- Fuel sulfur to PM (%): 2.2
- NOx (g/L fuel): 15.5

5.5 System converter

The system converter has been chosen a generic system converter which can be optimized by Homer Pro optimizer. Since the system is hybrid so the chosen converter is bi-directional the (i.e: DAC & ADC).

5.6 Battery system

Concerning the battery system, after many trials and errors and comparing the prices with the efficiency of the whole system the (EnerSys PowerSafe SBS 1500) has been chosen.

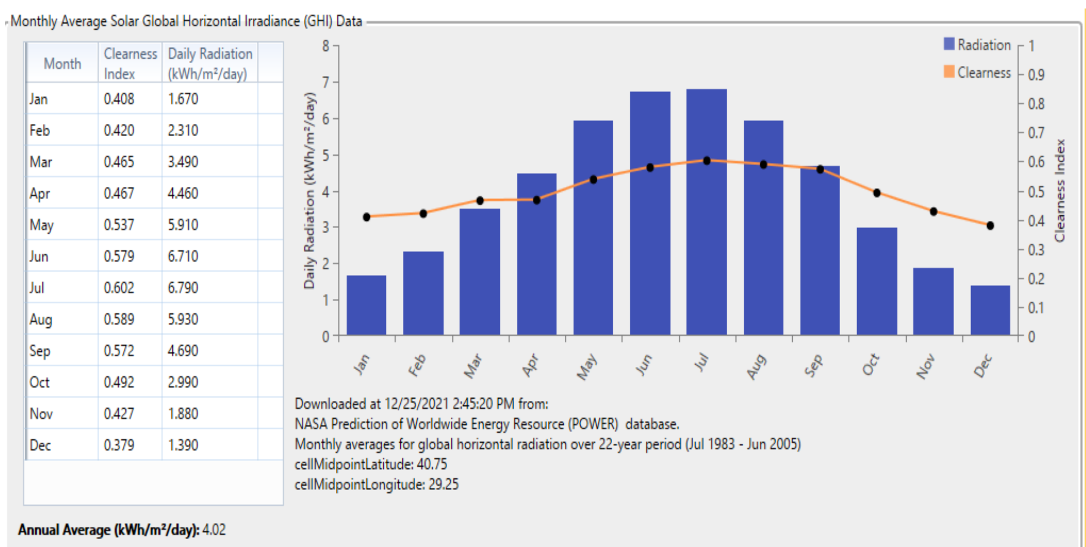
5.6.1 EnerSys PowerSafe SBS 1500 specifications

PowerSafe® sbs batteries deliver long-life, high-energy density and superior shelf life for a wide range of wireless and fixed-line communication applications. manufactured to the highest international standards, PowerSafe sbs batteries also offer high resistance to heat and lower internal resistance to support higher rate charging and discharging.

5.7 PV panels

5.7.1 Solar Energy Potential Of Büyükada Island

After putting the location of Büyükada on Homer Pro, the solar global horizontal irradiance (GHI) resource can be obtained as can be seen in figure 5.9. and it can give the monthly average of clearness index and daily radiation (KWh/m^2 /day).



Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.408	1.670
Feb	0.420	2.310
Mar	0.465	3.490
Apr	0.467	4.460
May	0.537	5.910
Jun	0.579	6.710
Jul	0.602	6.790
Aug	0.589	5.930
Sep	0.572	4.690
Oct	0.492	2.990
Nov	0.427	1.880
Dec	0.379	1.390

Figure 5.9 data of global horizontal irradiance

5.7.2 Chosing the type of the PV panel

Peimar SG310MBF is the type of panels used in this study especially after many trials and errors between efficiency and prices wise.

So the properties of this panel type are:

- Flat plate

- Rated capacity : 1 (KW)
- Operating temerature (°C): 25
- Efficiency (%): 19.1

5.8 Biomass Potential of Büyükada Island

After visiting Adalar Municipility in Büyükada and asking about the biomass potential, they said that all the trash now is taken from Büyükada to kucukbakkalkoy in Atasehir-Istanbul to be treated there. So the suggestion is to make a small factory in Büyükada to treat its own trash and all the recycling and exctracting the methane from the trash. This biogas can be a fuel to a biogas generator to give power to Büyükada. Hence the problem of trash in Adalar will be solved in this case.

The details about the trash is given from an employee from the Municipality, so the following Table 5.3 will give detailed information about all the monthly trash in Adalar from 2012 till 2020, and they consider that there is seven winter months indicated in blue in the table while for summer months are five indicated as yellow. So for the calculation the year 2019 is taken into consideration because in 2020 there was covid-19 so the normal numbers in several months are different from the other years because of the curfew and people were at staying at home. And since in Homer Pro the input of the of the biomass resource should be filled with the monthly average biomass data (tonnes/day) as shown in the following figure 5.10, the calculations are made based on it.

Table 5.3 The Average Monthly Amount Of Waste in Adalar District Between 2012- 2020

	2012	2013	2014	2015	2016	2017	2018	2019	2020			
ADALAR Districts	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)			
January	464,440.00	254,660.00	605,100.00	555,880	551,550	559,960	560,640.0	547,700.0	612,440.00	312517.62	10081.214	5161.5813
February	481,900.00	447,300.00	575,720.00	554,780	567,880	502,360	789,620.0	522,800.0	495,020.00	298309.68	10653.917	5454.8056
March	690,460.00	689,480.00	757,160.00	713,980	800,260	716,520	759,120.0	766,240.0	685,650.00	437216.54	14103.759	7221.1249
April	996,340.00	1,010,300.00	1,028,900.00	941,220	1,031,820	927,180	1,070,560.0	884,160.0	597,100.00	504501.7	16816.723	8610.1623
May	1,223,880.00	1,285,020.00	1,364,700.00	1,365,700	1,300,320	1,203,080	1,139,960.0	1,144,480.0	741,390.00	376533.92	12146.255	6218.8828
June	1,700,640.00	1,650,200.00	1,815,840.00	1,617,080	1,505,380	1,510,060	1,592,120.0	1,585,420.0	1,343,930.00	521603.18	17386.773	8902.0276
July	1,979,540.00	1,918,240.00	1,981,680.00	1,953,460	1,854,640	1,901,340	1,866,880.0	1,694,300.0	1,568,700.00	557424.7	17981.442	9206.4983
August	1,797,360.00	1,935,740.00	2,039,980.00	1,924,300	1,771,200	1,710,700	1,731,860.0	1,024,890.0	1,572,290.00	337188.81	11239.627	5754.689
September	1,248,120.00	1,354,640.00	1,408,320.00	1,432,000	1,272,020	1,261,040	1,205,260.0	1,139,960.0	1,273,570.00	375046.84	12098.285	6194.322
October	879,660.00	954,680.00	883,980.00	900,280	798,400	851,920	829,800.0	849,760.0	1,049,950.00	484873.06	16162.435	8275.1668
November	614,540.00	727,000.00	686,120.00	708,720	648,560	761,720	659,720.0	698,060.0		398313.04	12848.808	6578.5895
December	241,460.00	659,020.00	683,120.00	625,600	586,940	697,960	616,360.0	605,140.0		345292.88	11509.763	5892.9986
Total	12,318,340.00	12,886,280	13,830,620.00	13,293,000.00	12,688,970.00	12,603,840.00	12,821,900.00	11,462,910.0				
	2012	2013	2014	2015	2016	2017	2018	2019				
ADALAR Districts	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)	AMOUNT OF WASTE (Kg)				
r Period	4,368,800.00	4,742,440.00	5,220,100.00	5,000,460.00	4,985,410.00	5,017,620.00	5,285,820.00	4,873,860.0				
Summer Period	7,949,540.00	8,143,840.00	8,610,520.00	8,292,540.00	7,703,560.00	7,586,220.00	7,536,080.00	6,589,050.0				
	14552	16166	16052	15623	14478	14907	16119	15238				

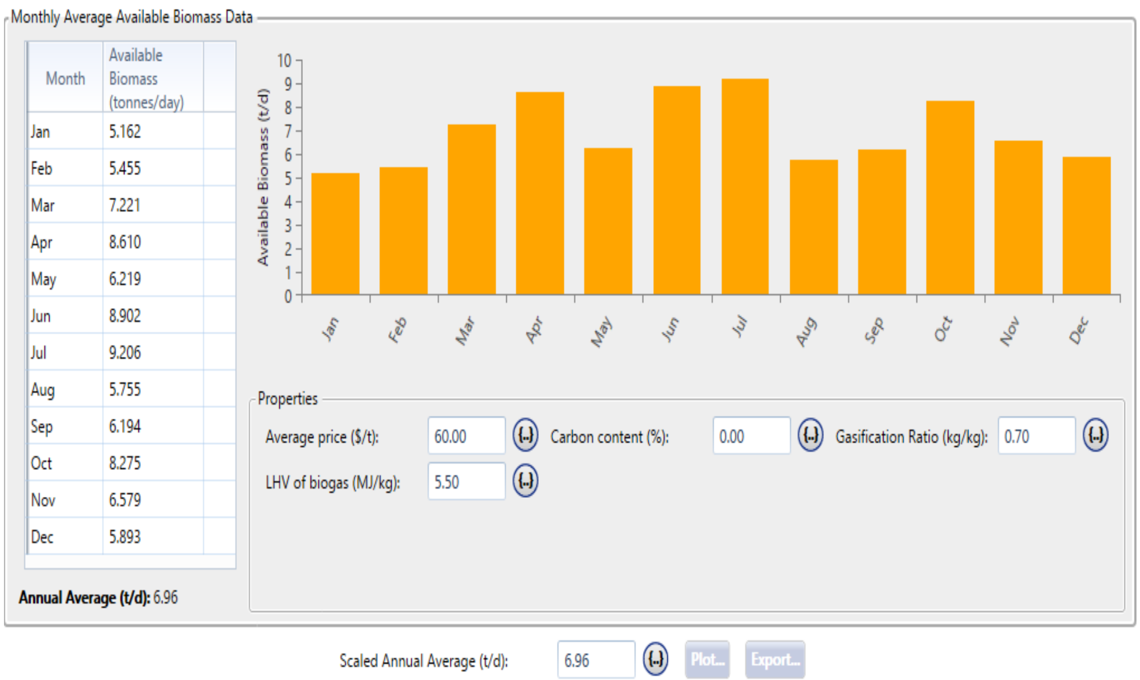


Figure 5.10 the data of the monthly average biomass.

Biogas Genset

After calculations mentioned above the biogas genset used in this study is the generic 500 KW.

The properties of this biogas genset are:

- Fuel: biogas
- Fuel curve intercept: 50 kg/hr
- Fuel curve slop: 2 kg/hr/KW

Emissions:

- CO (g/kg fuel): 2
- NO_x (g/kg fuel):1.25

5.9 Economical Aspects

Here is some mathematical rules needed for this design used by Homer Pro concerning economy.

Net Present Cost/NPC: The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each Component in the system, and of the system as a whole [60].

Levelized cost of energy/LCOE: HOMER defines the levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system [60].

Type: Output Variable

Units: $/kWh

Symbol: *COE*

To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electric load served, using the following equation:

$$COE = \frac{C_{ann,tot} - c_{boiler} H_{served}}{E_{served}}$$

Where:

$C_{ann,tot}$ = total annualized cost of the system [$/yr]

c_{boiler} = boiler marginal cost [$/kWh]

H_{served} = total thermal load served [kWh/yr]

E_{served} = total electrical load served [kWh/yr]

Capital cost: Fixed, one-time spending incurred on the purchase of land, buildings, construction, and equipment employed in the manufacturing of goods or the providing of services are referred to as capital costs. To put it another way, it's the overall cost of bringing a project to an economically viable state [60].

Salvage: is the value is the value remaining in a component of the power system at the end of the project lifetime. HOMER assumes linear depreciation of components, meaning that the salvage value of a component is directly proportional to its remaining life. It also assumes that the salvage value depends on the replacement cost rather than the initial capital cost and includes prorated maintenance costs from the last event to the end of the project [60].

HOMER calculates salvage value using the following equation:

$$S = C_{rep} \cdot \frac{R_{rem}}{R_{comp}}$$

R_{rem}, the remaining life of the component at the end of the project lifetime, is given by:

$$R_{rem} = R_{comp} - \left(R_{proj} - R_{rep}\right)$$

R_{rep}, the replacement cost duration, is given by:

$$R_{rep} = R_{comp} \cdot \mathrm{INT}\left(\frac{R_{proj}}{R_{comp}}\right)$$

other
definitions:

C_{rep}	= replacement cost [$]
Rcomp	= component lifetime [yr]
Rproj	= project lifetime [yr]

INT() = a function that returns the integer amount of a real number; for example, INT(6.843) = 6

HOMER assumes that salvage value accrues at the end of the project lifetime

The replacement cost: is the cost of replacing a Component at the end of its lifetime, as specified by Lifetime parameter in the Component model. This cost can be different than the initial capital cost for several reasons:

• Not all of the Components require replacement at the end of their lives. For example, the wind turbine nacelle might need replacement but the tower might not.

• The initial capital cost might be reduced or eliminated by a donor organization, but the replacement cost might not be reduced.

• You might want to account for the fixed costs (e.g., travel cost) of a visit to the site. At initial construction, these costs are shared by all Components, but at replacement time they might not be shared.

• You might want to account for a reduction over time in the purchase cost of a particular technology [60].

The Operation and Maintenance (O&M): is the cost of a component is the cost associated with operating and maintaining that component. The total O&M cost of the system is the sum of the O&M costs of each system component.

For most components, you enter the O&M cost as an annual amount. For a generator, you enter the O&M cost as an hourly value, and HOMER multiplies that by the operating hours per year to calculate the annual O&M cost.

The grid O&M cost is the annual cost of buying power from the grid minus any revenue earned from selling power to the grid.

HOMER classifies miscellaneous annual costs, such as the system fixed O&M cost, and penalties, such as emissions penalties and the capacity shortage penalty, as other O&M cost.

HOMER displays the O&M costs on the Cost Summary and Cash Flow tabs of the Simulation Results window [60].

The operating cost: is the annualized value of all costs and revenues other than initial capital costs [60].

Type: Output Variable

Units: $/yr

Symbol: $C_{oper,tot}$

HOMER uses the following equation to calculate the operating cost:

$$C_{operating} = C_{ann,tot} - C_{ann,cap}$$

where:

$C_{ann,tot}$ = the total annualized cost [$/yr]

$Cann,cap$ = the total annualized capital cost [$/yr]

6. RESULTS AND DISCUSSION

Homer Pro can generate many designs based on the configuration and the optimization of the system, we selected two of those designs one of the designs contains 100% renewable energy using wind turbine, solar panels, biomass, while the other one contains same as the previous one but with diesel generator. The comparison of both of the schematic and the architecture is discussed further in the following chapter.

6.1 The System Architecture and Schematic

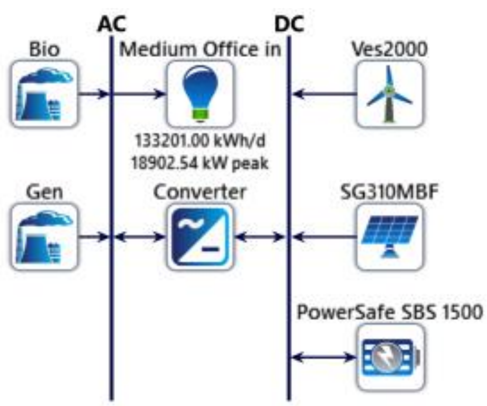


Figure 6.1 Schematic of a microgrid with a diesel generator

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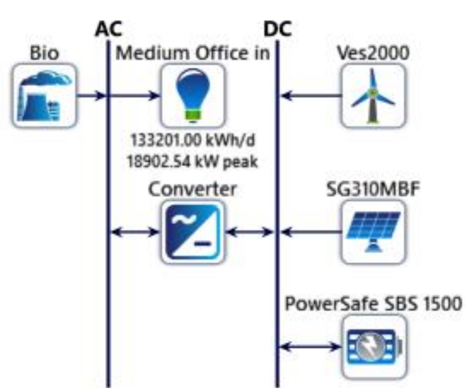

Figure 6.2 Schematic of a microgrid w/o diesel generator

Table 6.1 System Architecture with Diesel Generator

Component	Name	Size	Unit
Generator #1 (Biogas)	Generic 500kW Biogas Genset	500	kW
Generator #2 (diesel)	Autosize Genset	21,000	kW
PV	Peimar SG310MBF	44,614	kW
Storage	EnerSys PowerSafe SBS 1500	5,719	strings
Wind turbine	Vestas V110-2.0	1	ea.
System converter	System Converter	17,085	kW

Table 6.2 System Architecture w/o Diesel Generator

Component	Name	Size	Unit
Generator	Generic 500kW Biogas Genset	500	kW
PV	Peimar SG310MBF	191,841	kW
Storage	EnerSys PowerSafe SBS 1500	33,729	strings
Wind turbine	Vestas V110-2.0	1	ea.
System converter	System Converter	19,290	kW

6.2 Cost Summary and Net Present Cost (NPC)

Homer while designing systems it also generates cost summary and net present cost (NPC) for every project. The cost summary consists of capital, operating, replacement, salvage and the resource and the total cost of the project and for each component used in the system while the NPC represent the cost of each component since the project is started till the last day for 20 years, so the cost summary and the NPC for the suggested design with diesel generator and without diesel generator is shown in tables 6.3 and 6.4.

Table 6.3 NPC with Diesel Generator

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Autosize Genset	$10.5M	$5.07M	$2.65M	-$2.42M	$36.0M	$51.8M
EnerSys PowerSafe SBS 1500	$4.66M	$25.6M	$1.44M	-$77,2	$0.00	$31.6M
Generic 500kW Biogas Genset	$1.50M	$78,729	$0.00	-$111,7	$200,123	$1.67M
Peimar SG310MBF	$29.0M	$5.77M	$0.00	-$1.16M	$0.00	$33.6M
System Converter	$5.13M	$0.00	$2.17M	-$409,2	$0.00	$6.89M
Vestas V110-2.0	$1.88M	$485,661	$598,873	-$337,5	$0.00	$2.63M
System	$52.7M	$37.0M	$6.86M	-$4.51M	$36.2M	$128M

Table 6.4 NPC w/o Diesel Generator

Name	Capital	Operating	Replacement	Salvage	Resource	Total
EnerSys PowerSafe SBS 1500	$27.5M	$151M	$1.85M	-$348,1	$0.00	$180M
Generic 500kW Biogas Genset	$1.50M	$3,103	$0.00	-$148,2	$7,092	$1.36M
Peimar SG310MBF	$125M	$24.8M	$0.00	-$4.98M	$0.00	$145M
System Converter	$5.79M	$0.00	$2.46M	-$462,1	$0.00	$7.78M
Vestas V110-2.0	$1.88M	$485,661	$598,873	-$337,5	$0.00	$2.63M
System	$161M	$176M	$4.90M	-$6.27M	$7,092	$336M

6.3 Electrical Summary

Electric summary of the system consists of both excess electricity, unmet electric load and capacity shortage as long as the production of the system. Table 6.5 represents the excess and unmet electricity during the year and the capacity shortage, while 6.6 represent the percentage of electrical production by all the system components throughout the year.

Table 6.5 Excess and Unmet energy

Quantity	Value	Units
Excess Electricity	25,210,058	kWh/yr
Unmet Electric Load	0	kWh/yr
Capacity Shortage	0	kWh/yr

Table 6.6 Production Summary of the system

	Production (kWh/yr)	Percent
Peimar SG310MBF	59,763,444	77.6
Generic 500kW Biogas Genset	85,227	0.111
Autosize Genset	10,977,662	14.3
Vestas V110-2.0	6,160,842	8.00
Total	76,987,174	100

6.4 Generator: Generic 500kW Biogas Genset

Using the statistics from the biomass table in chapter 5 and the Homer Pro so the annual electric production is 85227 KWh/year. Table 6.7 and table 6.8 represents the fuel summary and the genset statistics for a biomass 500 KW generator respectively. And based on the numbers, fuel consumption, energy output and input the design and statistics the genset can changed for the chosen numbers and for the chosen design the values are shown in the tables below.

Table 6.7 Generic 500kW Biogas Genset Fuel Summary

Quantity	Value	Units
Fuel Consumption	258	tons/yr
Specific Fuel Consumption	2.12	kg/kWh
Fuel Energy Input	275,923	kWh/yr
Mean Electrical Efficiency	30.9	%

Table 6.8 Generic 500kW Biogas Genset Statistics

Quantity	Value	Units
Hours of Operation	203	hrs/yr
Number of Starts	98.0	starts/yr
Operational Life	98.5	Yr
Capacity Factor	1.95	%
Fixed Generation Cost	65.5	$/hr
Marginal Generation Cost	0.171	$/kWh

6.5 Generator: Autosize Genset (Diesel)

This section shows the study of the diesel generator under consideration, table 6.9 shows the electrical summary of the generator that consist of the electricity production minimum and the maximum electricity output of the diesel generator. Table 6.10 shows the fuel summary, fuel consumption, fuel energy input, efficiency output of the diesel generator. Table 6.11 is about the generic statistics that consist of the operational hours and life, capacity factor, and Fixed Generation Cost with Marginal Generation Cost. While table 6.12 represents the emissions by this diesel generator.

Table 6.9 Autosize Genset (Diesel) Electrical Summary

Quantity	Value	Units
Electrical Production	10,977,662	kWh/yr
Mean Electrical Output	17,621	kW
Minimum Electrical Output	5,250	kW
Maximum Electrical Output	21,000	kW

Table 6.10 Autosize Genset Fuel Summary

Quantity	Value	Units
Fuel Consumption	2,782,372	L
Specific Fuel Consumption	0.253	L/kWh
Fuel Energy Input	27,378,544	kWh/yr
Mean Electrical Efficiency	40.1	%

Table 6.11 Autosize Genset Statistics

Quantity	Value	Units
Hours of Operation	623	hrs/yr
Number of Starts	196	starts/yr
Operational Life	24.1	yr
Capacity Factor	5.97	%
Fixed Generation Cost	1,638	$/hr
Marginal Generation Cost	0.236	$/kWh

Table 6.12 emissions from the diesel generator

Pollutant	Quantity	Unit
Carbon Dioxide	7,283,178	kg/yr
Carbon Monoxide	45,910	kg/yr
Unburned Hydrocarbons	2,003	kg/yr
Particulate Matter	278	kg/yr
Sulfur Dioxide	17,835	kg/yr
Nitrogen Oxides	43,127	kg/yr

6.6 PV: Peimar SG310MBF

for this section the solar panel used here is the Peimar310MBF, so the electrical summary of this panel is shown in table 6.13 along with the minimum and maximum output, hours of operation and levelized cost of energy. While the table 6.14 consist of the statistics of this panel into this design like the Rated Capacity, mean Output, Capacity Factor and Total Production.

Table 6.13 PeimarSG310MBF Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	47,567	kW
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0435	$/kWh

Table 6.14 Peimar SG310MBF Statistics

Quantity	Value	Units
Rated Capacity	44,614	kW
Mean Output	6,822	kW
Mean Output	163,735	kWh/d
Capacity Factor	15.3	%
Total Production	59,763,444	kWh/yr

6.7 Wind Turbine: Vestas V110-2.0

For the electrical summary of the wind turbine VESTAS V110-2.0, the table 6.15 represents the minimum and maximum output, the percentage of the wind penetration, hours of operation with the levelized cost of energy. While the table 6.16 shows the wind turbine statistics for this design like the Total Rated Capacity, Mean Output, Capacity Factor and the Total Production

Table 6.15 Vestas V110-2.0 Electrical Summary

Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	703	kW
Capacity Factor	35.2	%
Total Production	6,160,842	kWh/yr

Table 6.16 Vestas V110-2.0 Statistics

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	2,002	kW
Wind Penetration	12.7	%

Hours of Operation	7,973	hrs/yr
Levelized Cost	0.0330	$/kWh

6.8 Storage: EnerSys PowerSafe SBS 1500

Since our microgrid operates in islanded mode so we need battery backup system, the table 6.17 and 6.18 shows the properties and results data for our energy storage system. The quantities in table 6.17 of the Batteries, String Size, Strings in Parallel and the Bus Voltage is represented. While the table 6.18 represents the energy in and out that is the charging and discharging cycle for the batteries, annual losses and the average energy cost for the storage system.

Table 6.17 EnerSys PowerSafe SBS 1500 Properties

Quantity	Value	Units
Batteries	5,719	qty.
String Size	1.00	batteries
Strings in Parallel	5,719	strings
Bus Voltage	12.0	V

Table 6.18 EnerSys PowerSafe SBS 1500 Result Data

Quantity	Value	Units
Average Energy Cost	0.102	$/kWh
Energy In	18,863,405	kWh/yr
Energy Out	18,315,190	kWh/yr
Storage Depletion	17,959	kWh/yr
Losses	566,174	kWh/yr
Annual Throughput	18,596,258	kWh/yr

6.9 Converter: System Converter

The configuration and the electrical and statistics for the system converter as shown in table 6.19 and 6.20.

The energy in and out with the hours of operation and losses is shown in 6.19, while in 6.20 the minimum and maximum output with the mean output and capacity are represented.

Table 6.19 System Converter Electrical Summary

Quantity	Value	Units
Hours of Operation	8,241	hrs/yr
Energy Out	43,732,250	kWh/yr

Energy In	46,033,948	kWh/yr
Losses	2,301,697	kWh/yr

Table 6.20 System Converter statistics

Quantity	Value	Units
Capacity	17,085	kW
Mean Output	4,992	kW
Minimum Output	0	kW
Maximum Output	15,534	kW
Capacity Factor	29.2	%

The system converter is a bi-directional converter and it consist of both inverter and rectifier when the load is connected or getting powered by the DC bus bar the inverter is operational as shown in figure 6.3, while when the system is connected to AC bus bar the rectifier is operational as shown in figure 6.4.

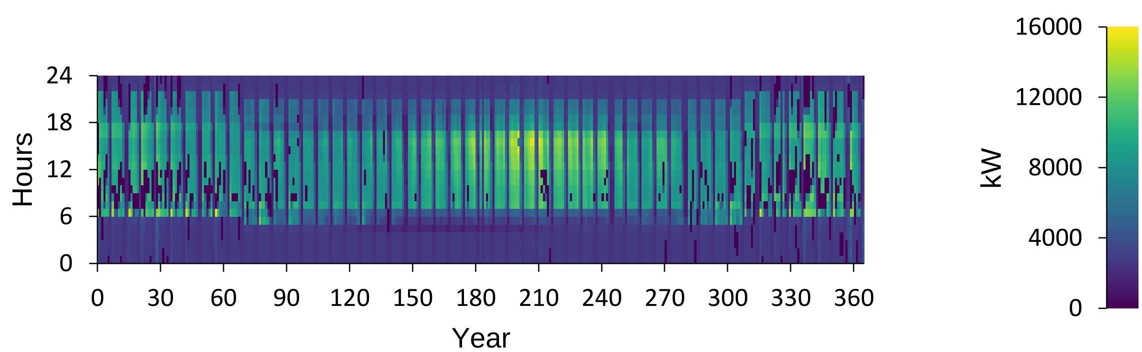

Figure 6.3 System Converter Inverter Output (kW)

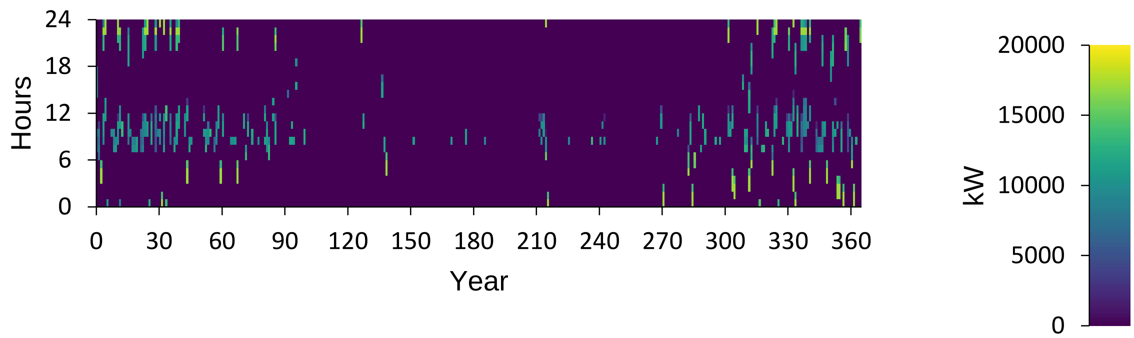

Figure 6.4 System Converter rectifier Output (kW)

7. CONCLUSION

Electricity is the most important form of energy in the present day, yet it is a resource that must be consumed as quickly as it is created. As a result, modeling the economics and designing of electricity generation is more difficult than modeling the economics of other industries for the same reason. The importance of accurate modeling cannot be overstated since it serves as the foundation for future investment decisions. Renewable energy sources are frequently employed as a power system's alternative generation unit, and growing utilization of these sources has several benefits. Investigating the economics and the design of Microgrid systems based on renewable energy sources, which are now of significant interest, will be critical in appraising future energy expenditures.

In the last decade, most of the governments are making big steps towards decarbonization, zero emissions and reducing the natural gas consumption since it is decreasing through time, hence it is recommended to establish microgrids based on renewable energy sources to achieve this goal. Based on that, this study is made to decrease the natural gas by providing power to the island and to get rid of the trash totally from all Adalar through waste treatment and extracting the biogas which can be fuel to generate electricity.

In this study Homer Pro is used to design an islanded mode microgrid for the Büyükada Maden Mah., the results gotten are, the levelized cost of energy is 0.2$/KWh and the NPC of the design is around 128 million $ around (85% renewable), with the components used: wind turbine (VESTAS V110 2.0), PV panels (peimar310MBF), autosize genset (diesel), a 500 KW biogas genset for biomass, battery system it has been used the (enersys powersafe SBS 1500), which is more convenient than the other design mentioned, the same configuration but without the diesel generator (100%

renewable), which cost Around 338 million $ with 0.53$/KWh levelized cost of energy, which is almost triple the price with the same configuration with the diesel generator.

According to the findings of the study, renewable energy source power plants have account for the majority of investments made in Turkey in recent years. The ratio of wind, solar, geothermal, and biomass power plants in these sources, in particular, rises higher than other sources. Taking into account Turkey's current capacity, the cost of spreading renewable energy sources plants is predicted to steadily reduce. As evidence, the International Renewable Energy Agency's (IRENA) yearly energy cost reports reveal that the costs of producing energy from renewable sources continue to fall with each passing year. As the cost of electricity falls, the percentage of renewable energy-based power plants grows.

It can be used in future more sophisticated approach by using machine learning for the production and renewable output and the load profile, we can also have different microgrids for other islands located nearby which can form a network of microgrid connected one to another. The approach can be to connect this microgrid to the national grid and exporting the excess of energy from Büyükada to the national grid and hence reducing the conventional load of the national grid.

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