MANAGEMENT OF DUHOK GOVERNORATE ENVIRONMENT BY GENERATING SUSTAINABLE SOLUTIONS (ROOFTOP PHOTOVOLTAIC SYSTEMS) IN BUILDINGS INSTEAD OF REGULAR ELECTRICITY: ENVIRONMENT, MANAGEMENT, AND TECHNO-ECONOMIC EVALUATIONS

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AHMED MOHAMMED AHMED AHMED: MANAGEMENT OF DUHOK GOVERNORATE ENVIRONMENT BY GENERATING SUSTAINABLE SOLUTIONS (ROOFTOP PHOTOVOLTAIC SYSTEMS) IN BUILDINGS INSTEAD OF REGULAR ELECTRICITY: ENVIRONMENT, MANAGEMENT, AND TECHNO-ECONOMIC EVALUATIONS

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Population growth and increasing demand for energy have been causing severe environmental problems all over the world. This research is done to find a suitable management way to improve the environmental condition, develop sustainable and economical solutions. This study focused on using Rooftop Photovoltaic Systems for the first time in Duhok governorate, Iraq, due to the rapid growth in the governorate and the great demand for energy, and the high energy production costs.

Four regions were chosen in Duhok governorate to install photovoltaic systems. The NASA database as a source for assessing solar energy potential were used. The results show that these areas have enormous potential and annual solar radiation to produce solar energy. The RETScreen expert evaluated the electricity production potential of PV systems. In addition, an economic study of 5kW capacity for grid-Connected rooftop PV projects was carried out in all selected regions.

Depending on the financial results and indicators, Rooftop Photovoltaic Systems can be a sustainable and efficient solution to improve the environment and economically installable in the Duhok governorate.

***Keywords**:* Solar energy, Iraq, Rooftop Photovoltaic Systems, Renewable energy, NASA database, RETScreen expert

ÖZET

Nüfus artışı ve artan enerji talebi tüm dünyada ciddi çevre sorunlarına neden oluyor. Bu araştırma, çevre koşullarını iyileştirmek, sürdürülebilir ve ekonomik çözümler geliştirmek için uygun bir yönetim yolu bulmak için yapılır. Bu çalışma, valilikteki hızlı büyüme ve yüksek enerji talebi ve yüksek enerji üretim maliyetleri nedeniyle Irak'ın Duhok vilayetinde ilk kez (Çatı Tipi Fotovoltaik Sistemler) kullanımına odaklanmıştır.

Fotovoltaik sistemleri kurmak için Duhok vilayeti nde dört bölge seçildi. Güneş enerjisi potansiyelini değerlendirmek için bir kaynak olarak NASA veritabanı kullanıldı. Sonuçlar, bu alanların güneş enerjisi üretmek için muazzam bir potansiyele ve yıllık güneş radyasyonuna sahip olduğunu gösteriyor. RETScreen expert, PV sistemlerinin elektrik üretim potansiyelini değerlendirdi. Buna ek olarak, seçilen tüm bölgelerde şebekeye bağlı çatı üstü PV projeleri için 5kW kapasiteli bir ekonomik çalışma gerçekleştirildi.

Finansal sonuçlara ve göstergelere bağlı olarak, Çatı Üstü Fotovoltaik Sistemleri çevreyi iyileştirmek için sürdürülebilir ve verimli bir çözüm olabilir ve Duhok vilayetinde ekonomik olarak kurulabilir.

Anahtar Kelimeler: *Güneş enerjisi, Irak, Çatı Üstü Fotovoltaik Sistemler, Yenilenebilir enerji, NASA veritabanı, RETScreen Expert*

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INTRODUCTION

1.1 Background

Nowadays, there is an increasing energy demand, various energy production methods are used, and various world problems such as environmental and economic problems are increasing because of these energy production methods (Burton, 2019).

The methods used at present to produce energy are the methods that negatively affect our world today. Common methods of producing energy are coal, gas, oil, etc. This is done by burning fossil fuels to generate power. However, the use of fossil fuels has poisoned the atmosphere and contributed to climate change due to the pollution of greenhouse gases. In another view, there is a huge cost the economic aspect that is used in many countries. As for the healthy aspect, the use of fossil fuels causes the spread of many diseases due to the emission of thermal gases (Chanda et al., 2019; Daniels, 2009).

The environmental issues caused by rising fossil fuel use have led scientific researchers to research safe alternative energy sources. Many researchers have found that renewable energy can solve many problems that face us in energy production and be a reliable method for generating energy (Rogers et al., 2019; Chen et al., 2019).

Renewable energy is the energy that we take from natural sources, and it is called clean energy. Renewable energy is taken from some sources such as sunlight, geothermal heat, water, wind, and storms. Saving this energy depends on time and weather. We take the largest proportion of renewable energy from the sun, directly or indirectly. The energy taken from the sun can be by its light or energy directly for lighting homes and buildings, heating, generating electricity, heating, and even cooling with solar energy (Cali et al., 2018; Ahmed et al., 2018).

Day by day, renewable energy is increasingly spreading and becoming critical in tackling air pollution and expanding ways to obtain high-quality energy. From an economic point of view, all countries are trying to develop in the field of energy production, mostly renewable energy, because it provides electricity at reasonable prices, its cost is very low, and most of its technologies are clean and reliable as a sustainable solution in the future (Murray et al., 2019).

Electricity production in most countries is a major cause of air pollution. The production of electricity from fossil fuels leads to CO2 emissions, and this emission leads to climate change (Caglayan et al., 2019; Cali et al., 2018).

Climate change is the most serious environmental problem and life-threatening disaster on the earth's crust. Global warming is also known as this occurrence. Global warming was discovered in the middle of the twentieth century. From the beginning of its discovery, serious work was started to find appropriate solutions to eliminate this phenomenon and reduce its adverse effects. According to the World Health Organization, in 2000 global warming has killed 150,000 people in one year, and this figure could double in the next decade (Ibrahim et al., 2020; Ahmed et al., 2018).

In Iraq, most energy production depends on providing electricity using thermal power plants that use fossil fuels, and there are many economic problems because they cost a large amount and extract a large amount of CO2 emissions, and these stations are very disturbing to produce a loud and unsuitable sound that reduces the generosity of the city, and there are many possibilities for fires due to a large number of wires and their lack of alignment (Mahmood et al., 2020; Darwish et al., 2019; Al-damook et al., 2017; Lattieff et al., 2019)

1.2 The Concept of Renewable Energy

Renewable energy is one of the most recent types of energy globally, and various types of it have been discovered recently and have been continuously developed. Renewable energy is usually dependent on natural resources. These resources include sunlight, biomass, winds, tides, geothermal, and waves (Ibrahim et al., 2020; Krzyscin et al., 1997).

Renewable energy is sustainable environmental energy, unlike non-renewable energy based on petroleum and fossil fuels, which causes climate change and environmental damage. Nonrenewable energy waste causes major pollution, which affects the organisms on the earth's surface, including humans. It causes many dangerous diseases that affect human health and the emergence of many diseases that didn't exist before. Thus, renewable energy will help eliminate the problems that face us, affecting our world negatively (Paletto et al., 2019; Nazir et al., 2019; Belsk, 1994).

1.3 Advantage and Disadvantage of Renewable Energy

The most essential advantages of renewable energy (Nelson et al., 2018):

1. Technologies that use renewable energy are directly related to the environment. Especially from the sun and Wind. This is the reason renewable energy is considered waterproof.
2. Renewable energy does not require continuous maintenance, and this is why it distinguishes renewable energy from fossil fuels because it saves less time and less maintenance.
3. Renewable energy helps in organizational and economic development because it will save maintenance costs and operating costs.
4. Renewable energy is beneficial with the healthy environment that we need, as it does not extract any greenhouse gases and air pollutants or a tiny percentage of them.
5. It offers unemployed persons a variety of work openings.
6. Protects the degradation and extinction of air, seawater, wetlands, and fisheries.

Disadvantages of renewable energy (Nelson et al., 2018):

1. In many places, renewable energy cannot be reliable in the presence of many problems, whether in temperatures or duration of sunshine, etc.
2. Needs huge expense at the beginning of the site installation.

3. To install a suitable site requires a lot of space, for this reason, it is not possible to save in many places.
4. In commercial terms, it is not always a successful option.
5. Renewable energy needs to be stored, and this requires a high cost.

1.4 Type of Renewable Energy Sources

At present, the most common renewable sources of energy are (Kemp, 2005; Dorsman et al., 2014):

Solar energy

We can give a simple definition of solar energy, which is the light and heat that we take directly from the sun, and we can harness this energy in different ways. We can use this energy by taking photovoltaics and converting it from light into electricity shown in Figure 1.1. Solar energy technology uses the sun s heat to form steam, hot water, etc.

Figure 1.1: Solar Energy, (Kayim et al., 2019)

Wind energy

Wind energy is a type of renewable energy because it took natural wind source and the wind energy process shows us the use of Wind to generate electricity. Wind turbines work to take mechanical energy from kinetic energy. By this, we deduce electricity from mechanical energy as in Figure 1.2.

Figure 1.2: Axis Wind Turbine, (Nelson and Starcher, 2018)

Geothermal energy

We can use many energy production methods and show us in this type of renewable energy that even the underground has a lot of water and steam in it that helps us to use it in useful ways for cooling and heating or generating clean electricity as shown in Figure 1.3.

Figure 1.3: Geothermal energy, (Dorsman et al., 2014)

Biomass energy

Biomass is a substance that extracts methane gas. The source of this substance is animals and plants. Methane gas is used in many countries as an alternative to natural gases to save electricity and household uses as shown in Figure 1.4.

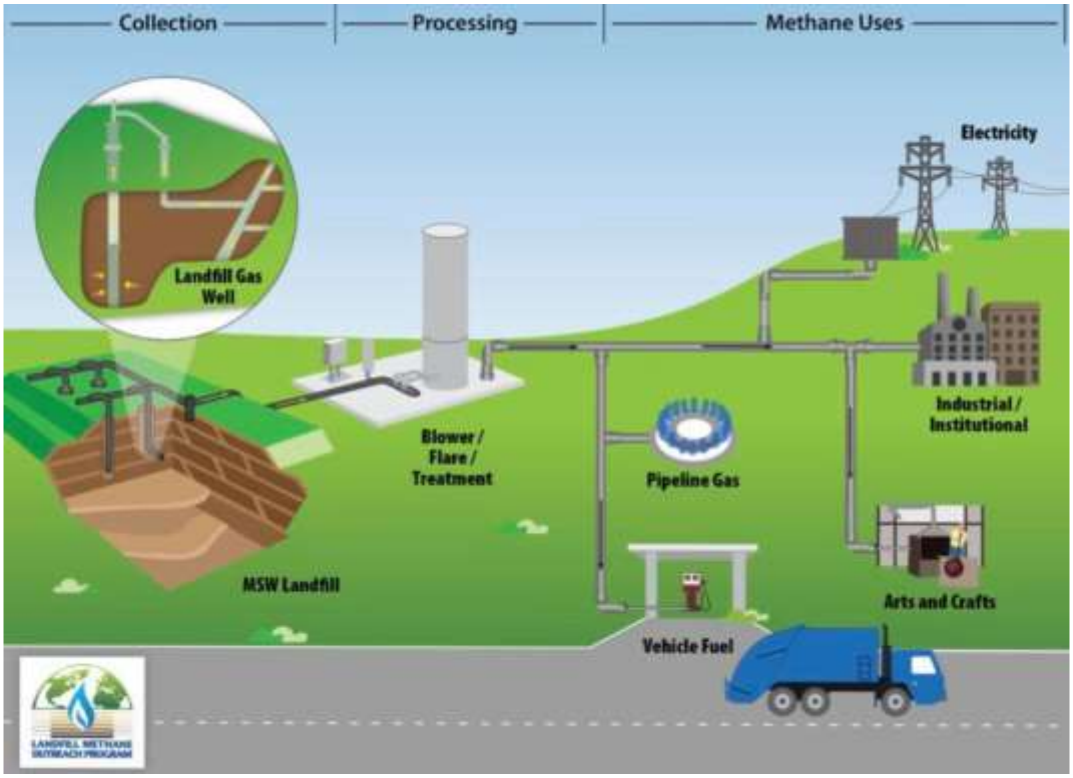

Figure 1.4: Biomass Energy process, (Dorsman et al., 2014)

1.5 Aim of the Study

The literature review findings reveal an apparent lack of proposed solar PV systems for households living in Iraq, especially in the northern part. According to the authors' analysis, no studies assess the feasibility of grid-connected residential rooftop PV systems in the region. Therefore, the thesis investigates the techno-economic and environmental sustainability of PV rooftop systems in Iraq, especially in the Duhok governorate. Besides, this study identified a small-scale 5 kW rooftop PV system in the city to solve the increasing demand and improve the quality of life in urban areas due to the city's rapid growth. Using RETScreen Expert software the environmental effects of residential rooftop photovoltaic systems are calculated. The selected city's solar energy potentials are analyzed based on the solar radiation data and air temperature collected in this research from the National Aeronautics and Space Administration

(NASA). The possibility of providing valuable inputs to the development of new policies and the growth of Iraq's photovoltaic energy market.

1.6 Research Outline

This chapter discusses the importance of renewable energy and its development in the world. Chapter 2, a discussion about the importance of solar energy and the types of solar panels. An illustration is also given on the approach used to illustrate solar energy's potential and design a 5 kW photovoltaic system to generate electricity in chapter 3. All the information on the materials and method, as well as on the area, is a study included in Chapter 4. Moreover, in Chapter 5 all results of a test of the proposed system are presented. At the end of the thesis, the conclusions are presented in Chapter 6.

CHAPTER 2

RENEWABLE ENERGY IN IRAQ AND LITERATURE REVIEW

2.1 Renewable Energy in Iraq

Iraq is located in the Eastern Mediterranean, with 437,072 square kilometers and a coastline of 58 km. The country has a population of 40 million. This site gives a strategic and global influence and acts as the first forum to link the world's countries from the international and commercial side. Iraq is one of the countries that enjoy a permanent wealth of renewable energies and does not use them despite their availability. Generally, renewable energy is the energy that is produced from sources that do not depend on fossil fuels such as gas, coal, and nuclear power. Renewable energy can also be defined as energy flows that are renewed at the same rate of use (Ibrahim et al., 2020; Rasham, 2016).

Iraq suffers from a crisis of electricity shortage, and we must work to solve this crisis to increase electrical demands. The Iraqi electricity system depends mainly on the large thermal energy from the gases emitted from the atmosphere. The Iraqi Ministry of Electricity announced that Iraq does not currently produce any renewable energy. Still, the Iraqi government signed contracts to produce 1,000 MW of solar energy in 2018, which led to an increase in about 2,000 MW by 2025. In 2019, the Iraqi Ministry of Electricity announced the launch of the first round of solar photovoltaic projects, power stations with a capacity of 755 MW, and inviting companies working in this field to participate, as the ministry identified the projects distributed in the governorates of Babel, Wasit, Karbala, and Muthanna. In Iraq, the use of solar energy, wind energy, and biomass is sufficient, but work to develop them can play an important role in the future of renewable energies in Iraq (Azabany et al., 2020; Hasoon, 2013; Hamdoon et al., 2020).

In general, renewable energy projects work to reduce the percentage of carbon dioxide in many countries. Therefore, in a country like Iraq, which has high temperatures in the summer, the government must establish advanced electrical stations (long-term) because the validity of producing electric energy in the available stations has also expired The rate of urbanization and the increase in the population that causes an increase in the levels of annual demand for electricity by 7-10%. Suppose the use of renewable energy in Iraq is done. In that case, it will lead to achieving self-sufficiency to reduce the import of electricity and gas, which costs Iraq from 2.5 to 2.8 billion dollars annually (Khalid et al., 2020; Amin et al., 2018).

Also, 48.11 % and 49.62 % of total electricity are produced by oil products and natural gas, according to IEA Electricity Information (2020), while hydropower and solar were exchanged by about 2.20 % and 0.07 % of total electricity in 2018 from just 2.6 percent in 2018 (Alasady, 2011; Kazem et al., 2012).

Figure 2.1 shows that Iraq's electrical production is mainly generated by oil products, natural gas, and hydropower.

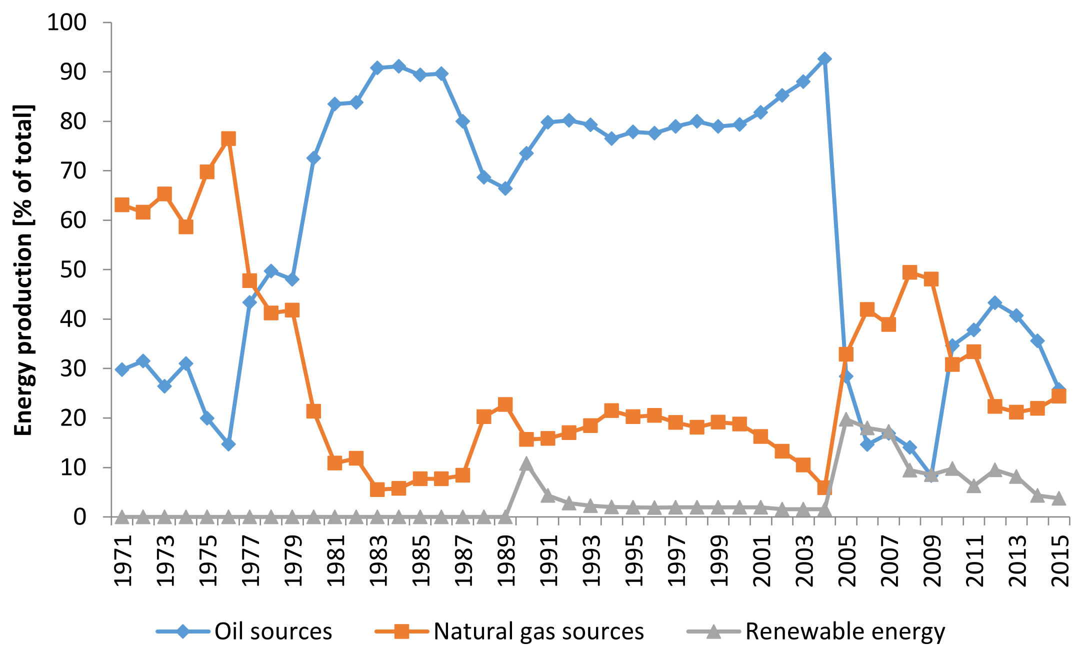

Figure 2.1: Electrical production in Iraq

2.1.1 Wind Energy

The Wind is considered the source of solar energy. The irregular heating creates winds. The sun's atmosphere, the anomalies of the earth's surface, and the earth's rotation. Patterns of wind flow are modified by the earth's topography, water bodies, and vegetative coverage. Modern wind turbines can use this flow of Wind or this Motion power to produce motion. Around electricity (Mahmood et al., 2020).

Wind turbines transform the Wind's kinetic energy into mechanical electricity. Might Strength: It is possible to use this mechanical strength for particular tasks (such as grain grinding or water pumping) or convert this mechanical method to various wind power technologies that can be used to power households, companies, and schools and the like. Wind turbines in theory Horizontal axis or vertical axis machines might be feasible, the first of these, however, has Come to the market to conquer. Increasingly, wind turbines are on offshore sites, deployed (Kazem et al., 2012).

The Wind is also a renewable energy source. Which plays a major role in reducing the effects of green gases and working to provide a reliable work environment and energy-efficient (Al-damook et al., 2017).

In Iraq, many studies have been undertaken to investigate wind energy. Many stations have been selected to analyze wind energy capabilities. The model supplied shows wind velocity has maximum values too many times especially in the midday and early morning hours and these maximum values ranged from 5 to 10 m/s. The Wind In summer, the velocity is greater than in winter, which is lucky. As electrical energy requirements increase in the summer increased cooling and ventilation loads compared to winter because it is possible to split Iraq into three territories. The territory accounts for 48 % of Iraq and has wind speeds that differ between 2-3 m/s. The second region accounts for 35 % of Iraq and has wind speeds range from 3.1 to 4.9 m/s. The third land represents 8 % of Iraq and has reasonably high wind speeds above 5 m/s (Hassoon et al., 2013).

Such experiments showed that the approximate energy densities for wind areas are as follows: 174 W/m2 in Al-Emarra, 194 W/m2 in Al-Nekhaib, 337 W/m2 in Al-Nekhaib, 194 W/m2 in

Kout, in Ana at 353 W/m2, and Al-Naseria at 378 W/m2. From these, as a result, the average energy of around 287.2 W/m2 can be achieved acquired.

Besides previous research and data collection in different Iraq regions, wind energy was distributed (as shown in Figures 2.2, 2.3, and 2.4) into three of the following sections (Southern Iraq, Middle of Iraq, and Northern Iraq).

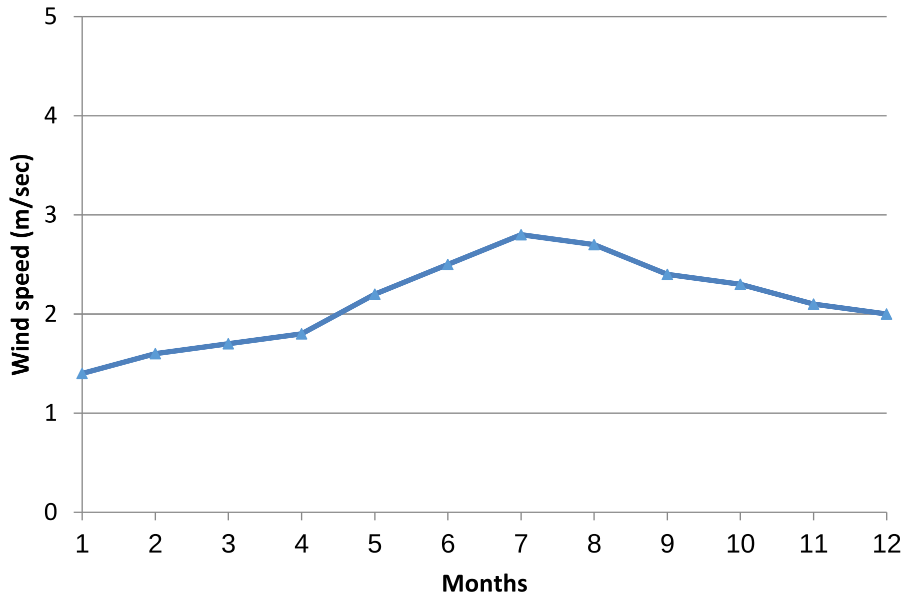

Figure 2.2: Average wind speed in Southern Iraq

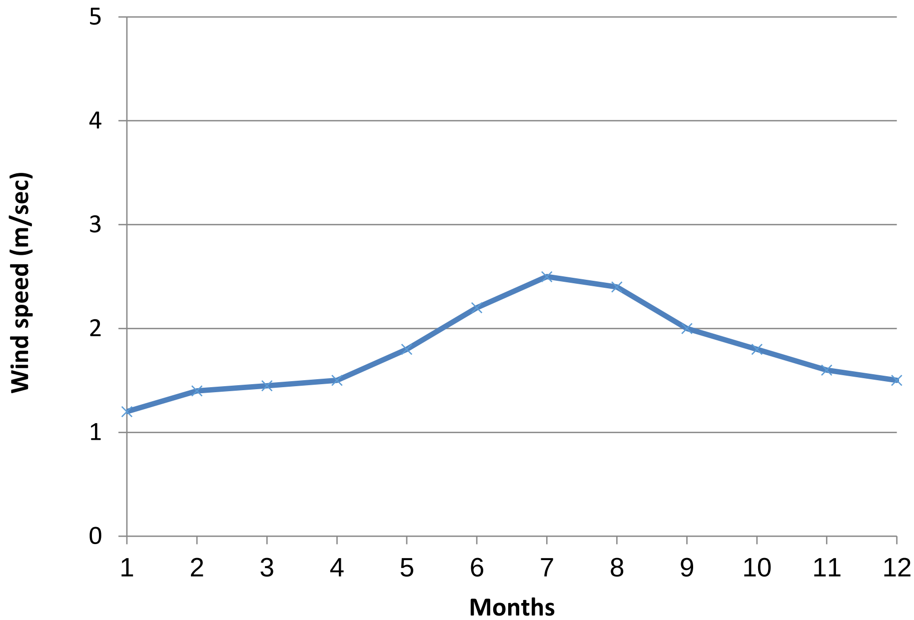

Figure 2.3: Average wind speed in the Middle of Iraq

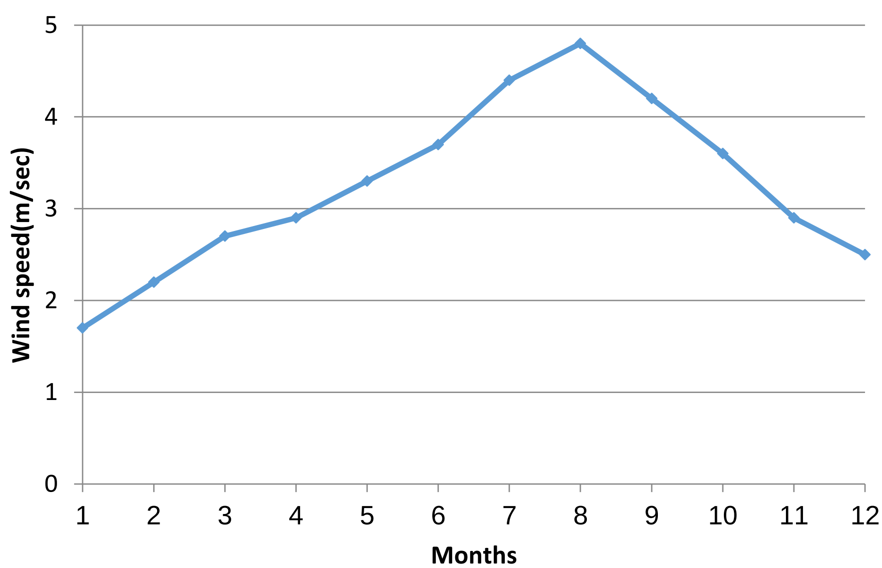

Figure 2.4: Average wind speed in Northern Iraq

2.1.2 Hydropower

Hydropower has always been an important source of energy in Iraq. Especially in the field of electricity generation. Before 1990, Iraq relied on hydropower to produce electricity, and the installed capacity of hydropower plants reached a production of 10200 MW in 32 stations. After the passage of time and the continuous wars in Iraq, the hydropower field was greatly affected and about 90% of the energy generation organizations in the country were destroyed (Hammid et al., 2017).

In 2002 serious attempts were made again to generate power, and 21% of the total electricity was taken from the two hydropower plants. In 2017, due to the rapid growth in the country and the great demand for energy, and the country's interest in producing electricity, his led to the production of (4059.9) terawatt-hours from 10 stations of hydropower, representing an estimate of 15% of the overall electricity production of 25,551.1 (Kayim et al., 2019).

The output volume of hydropower relies on the station's hydrology condition with water control in the dams and reservoirs. These stations use the difference in the water column's height in the dam and the facility's turbine's water flow rate.

The fact of hydropower in Iraq Organizational Mosul (Figure 2.5), pumped storage dam, new Hamrin Dam (Figure 2.6), Al Hindiya, Kufa and Dokan (Figure 2.7), and Derbandikhan (Figure 2.8), (Hammid et al., 2017). Stations in the province are scattered over ten hydroelectric stations around the major Mosul Dam. The overall output of its design is 1754 MW/h and a production volume of 3900000 MW/h.

The problems of hydroelectric power stations and complicating the ability to develop them:

- Continuous wars in the country and the destruction of a lot of hydropower stations.
- Rural agriculture is greatly affected by the lack of hydropower development for several reasons related to agriculture.
- The water infrastructure in many regions of the country is very poor.
- There is a problem in terms of security and special payments in this area.

Figure 2.5: Mosul Dam

Figure 2.6: Hamrin Dam

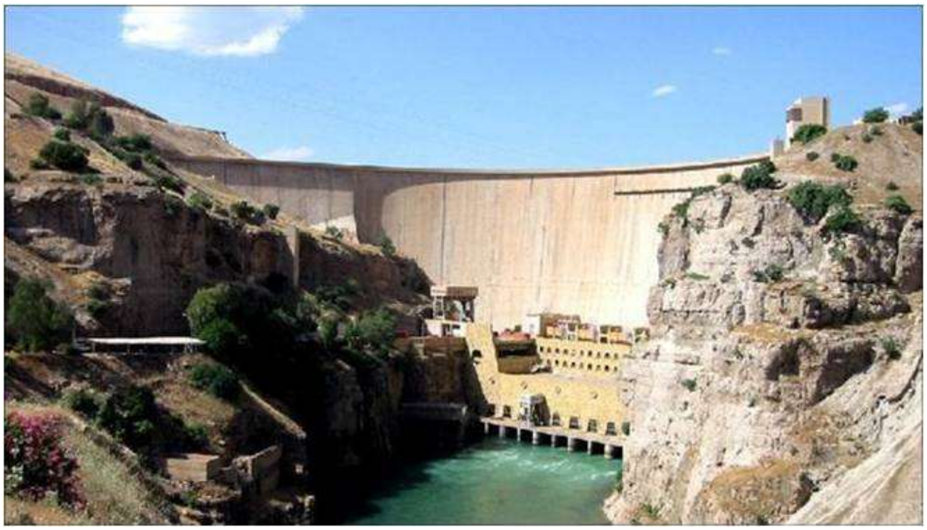

Figure 2.7: Dokan Dam

Figure 2.8: Derbandikhan Dam

2.1.3 Solar Energy

Scientific studies have confirmed that Iraq possesses abundant amounts of solar energy with wide sunlight throughout the year, as Iraq receives more than 3000 hours of solar radiation per year only in the capital, Baghdad. The sun's intensity varies every hour from 416 watts / m2 in January to 833 watts / m2 in June. In general, the duration of solar radiation ranges between 2800 to 3000 hours per year in the western and southern regions with horizontal radiation exceeding 6.5 to 7 kW in an hour / square meter per day, and this is what distinguishes the two areas for investment in building solar power stations (Al-Douri et al., 2016; AL-Waeli et al., 2017).

Based on Iraq's location, located in the global solar belt, every 100 square km is used from the western and southern deserts (the desert north and south), producing energy equivalent to 30 million tons of oil equivalent MTOE annually photovoltaic panels. This makes Iraq an ideal place to invest in solar energy and by 2030, 66 countries in the global solar belt could reach a combined solar PV capacity of 101 terawatts (Al-Waeli et a., 2018; Ibrahim et al., 2020).

After the energy crisis in 1973, a study of solar energy began in Iraq, where many studies were conducted to determine the rates of solar density representation in Baghdad. During that period, there were numerous studies and theories in Iraq. Studies began to study domestic water heaters and chillers that use solar energy and build theoretical models representing solar water heaters. The results showed the unity between the practical and theoretical results. The studies' focus shifted towards finding possible ways to improve solar energy generation applications (Abed et al., 2020; Lattieff et al., 2019).

(Muhammad Rasool, 2008) studied the potential use of solar energy in hydrogen production. Experimental investigations confirmed that the use of walls (turbine) can use solar energy during winter in Iraq. (Chaichan, 2009) demonstrated the success of the solar salt gradient basins and used the energy stored in the heating rooms. The validity of solar radiation data is vital for economic use in solar energy.

The state of solar energy in Iraq over the years, in the eighties, Iraq put in place a plan to develop solar energy to generate electric power. Whereas in 1982, the Renewable Energy Law was issued. After three decades, the first solar panels were installed on the Middle East roofs at the

Solar Energy Research Center in Al-Jadriya, Baghdad 1986. The presence of wars and economic sanctions greatly affected the renewable energy plans.

In 2009 the Iraqi Ministry of Electricity announced a plan to install six thousand solar street lights outside the grid to light the streets of Baghdad as part of a scheme to spend up to $ 106 billion and add 400 MW of solar and Wind power stations.

By 2016 the plan was abandoned due to the collapse in international oil prices. In 2017, interest in solar energy returned when the Iraqi government announced interest in building a partnership between the private and public sectors. By the end of 2018, the prices of photovoltaic units had decreased by 75% in the international market, which encouraged installing solar panels on rooftops outside the network to replace diesel generators and unsupported local energy managed by private companies (Amin et al., 2018).

In general, between 1991 and 2003 due to disturbance caused by destruction and sabotage, the network distribution system was down. The network must be modernized or replaced with a strong smart network because the old network is not suitable to support high power loads and huge losses through the handling of portable energy, as the smart grid adopts the concept of interaction between the consumer and the power generation and distribution network, and measures and balances the state of the power load during peak hours. It also manages the energy status of each region or user (Khasraw et al., 2019).

A smart network must be chosen to deal with the energy from various power generation stations, whether fuel, gas, PV or CSP, etc. And in the advanced era, the current system in Iraq must be updated using a new smart network that uses self-intelligence to manage energy distribution and consumption. It will be appropriate to integrate the energy generated from renewable energy sources into the network.

As shown in Figure 2.9, the possibilities of irradiation in all regions, in Iraq, the level of inclination of sunlight ranges from 6.5 to 5.07 (kWh /m2/day).

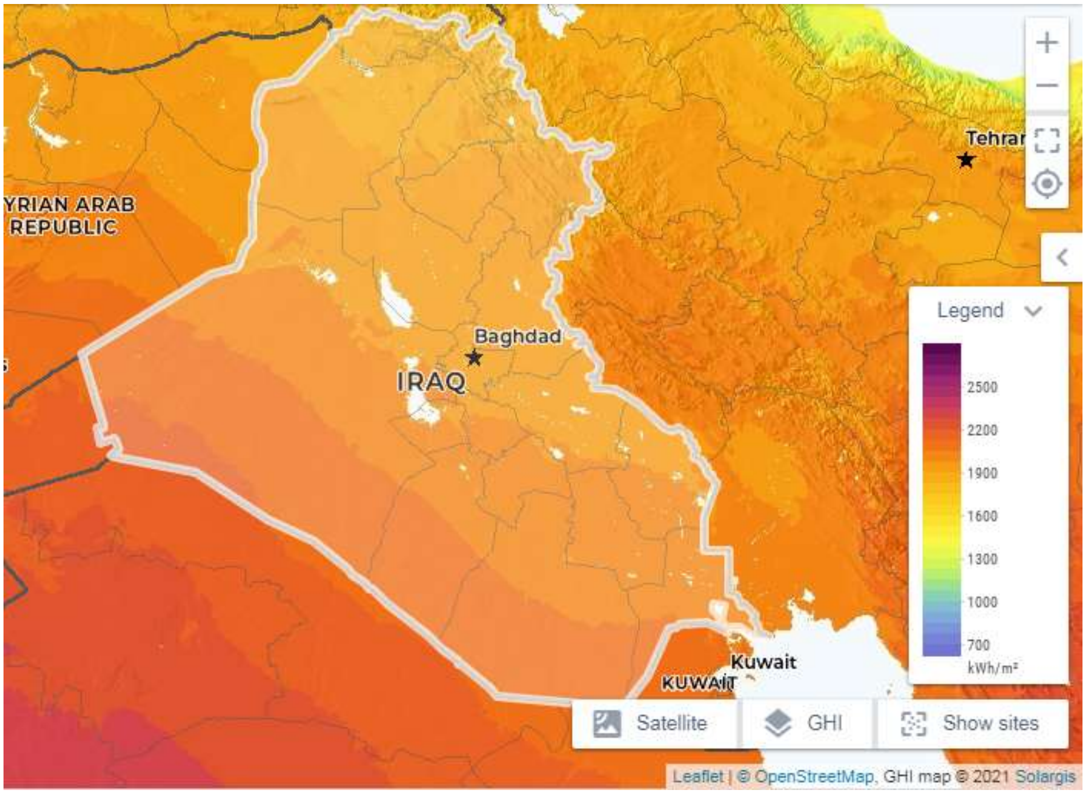

Figure 2.9: The potential of irradiation on an optimally inclined plane (kWh/ m2)

The fundamental characteristics of solar radiation in Iraq are summarized as follows:

- The annual changes ranged in the northern territories by roughly 300 percent, ranging in December and January from 7 MJ/m2 June to 23 MJ/m2. In the South's territory, the annual, Modifications ranged by nearly 200%, ranging from 13 MJ/m2.
- In December and January, in June and July, to 27 MJ/ m2. Inside the Central Territories' annual changes ranged by roughly 250 percent, which can be viewed as the annual average of improvements between the north and south areas.
- Solar radiation firmly descends from north to south and winter rises and summer falls. There's a whole lot of it, more uniform solar radiation coverage in the whole of the in autumn, Iraqi territory (from June to August).
- The fall in solar energy from east to west is Tiny and vulnerable to an error in measurement.

- Assessment of solar radiation relies on relationships resulting from Centered on data measured by meteorological stations in big towns and cities. Such sites produce less radiation. The nearby areas are also due to pollution, so the true pollution radiation levels are greater than those measured.

2.2 Literature Review

Besides et al. (2014) concluded that the solar energy system and hydropower system could be met as alternative energy sources to produce electricity and solve the problems existing in the country and the environment. It will be an appropriate solution to reduce CO_2 emissions.

Kayim et al., (2019) concluded that solar energy can produce in the range of 1800-23900 kWh / m2 and can be supplied for 10 hours per day. The study results confirmed that this percentage of energy production would be an appropriate solution to eliminate the country's electricity crisis.

Faleh et al. (2019) studied the characteristics of wind speed data analysis at the Salman Iraq site. The MLM method was used to show and describe the best wind distribution and the cumulative distribution function. Analysis of different wind turbine axle heights. It was found that at a height of 50 meters, the average wind speed was approximately 5.93 m / s, the density of this site was 219 watts / m, and 50% of the wind speed was more than 5 m / s, which helps to generate sufficient energy to produce electricity.

Ahmed, (2013) an investigation conducted on the potential of wind energy in northern Iraq. It collected data over three decades and selected five different sites for the potential of wind energy. The results indicated that in July, the wind speed in Tikrit is 4.0-4.5 (m / s), and this result can produce (13.5kW / h) on the maximum expected.

Ibrahim et al. (2020) used Boolean logical-AHP technology to search for the best location for installing the solar energy system in Dohuk, Iraq. They found that 68.5% of the city area can be used for solar energy stations according to the results.

Aziz et al. (2019) explored the feasibility, techno-economic, and environmental implications, of various hybrid schemes using HOMER software to provide electricity to a traditional Iraqi rural village. The findings revealed that the most economical system was PV/hydro/diesel/battery hybrid energy systems because of the low net present cost-benefit and high environmental efficiency level.

Hussain et al., (2019) presented a study on future perspectives on renewable energy and focused more on solar energy's potential to provide Iraq's required energy. They found that the country could use more solar energy than the present time and did not sufficiently use solar energy. And they found that it can be used in two ways, first as standalone stations and secondly as integrated thermal power plants. To get rid of the environmental and economic problems facing the country.

Salwan et al., (2010), proposed the hybrid system as a resource for power generation in three provinces in Iraq. MATLAB solver was used for PV observations in selected governorates and to achieve turbine and wind PV volumes. The results showed that it is possible to obtain sufficient energy from these sources in many villages and rural areas Due to high solar radiation. The results indicated that this system chose Basra as the best location for installing solar and wind energy systems.

Rasham, (2016) According to his study, it is evident in Iraq that there is a huge potential for using wind energy in many regions, and three regions in Iraq were researched to analyze the annual wind speed data. MATLAB software was used as a standard solution. Basra and Nasiriyah were selected as acceptable areas to connect with the power grid.

Ahmed et al. (2019) concluded that Iraq's solar energy can be a sustainable solution and a solution to its problems. The use of solar energy is one of the most appropriate solutions to eliminate the electricity shortage, especially its environmental problem and pollution.

Alduori et al., (2016) concluded that we can develop in the field of solar energy because in Iraq there are auxiliary tools, especially wind directions and friendly temperature, and their study of the variation in annual radiation levels was found. UV rays were found to constitute 3.25% of global radiation.

Alaa, (2011) studied the use of solar energy that could be an alternative outside of oil, and they found that the sun hours in Iraq exceed 3000 hours per year, and for this reason, Iraq can be a global source of clean energy.

Ali et al. (2017) studied the effects of climate change in Iraq and the three wars in the past 25 years and showed that they have negatively affected the country's infrastructure greatly. It was found in the results of the research that Iraq can use solar energy in different applications. It shows that Iraq is qualified to be a producer of all solar energy noses, produce electricity, get rid of problems in the country, and even issue electricity to neighboring countries, which is for appropriate weather conditions.

Al-Waeli et al., (2018) study confirmed that Iraq needs 20000 megawatts in the year 2020 due to its rapid growth and that the Iraqi government has met to use solar energy to solve the electricity crisis in the country. The government plans to use solar energy as a sustainable solution as it is environmentally friendly and free of charge in this way, it will be helpful in the fields of economic conservation.

Gaylan et al. (2020) used Boolean AHP and GIS to select a suitable site for solar energy in Erbil, Iraq. For their study, the following three scenarios are chosen, economic, environmental, and equal weight. The study identified 369 candidate sites for installing solar energy systems. The results indicated that 85% of the candidate sites are suitable for installing solar energy systems, especially in the southern and central regions.

Azabany et al. (2014) investigated the sources relied on for power generation in Iraq over the past three decades, and they showed that the largest proportion was fossil fuels. Thus it is a source of great concern for the future of the environment and the earth. And their study chose an area in the city of Erbil, Iraq to install the solar energy system to complement the increasing load of electricity demand in the city. The results confirmed that the city of Erbil, Iraq has an average of a good amount of solar radiation throughout the year, about 5.3 kWh / m2 / day. They concluded that the chosen area is very suitable for designing and installing a solar power system to generate 315 kW.

Khaled et al., (2020) concluded that the experimental and digital survey in the city of Dohuk for the hybrid solar PV thermal energy system within seven months to obtain the total temperature, water mass flow, sun density, and average wind speed. The experimental and numerical results were shown. An error of 2.36% was found between the two thermals. Whereas in May 2019, the highest density (72.1%) of PV / T complex occurred and the lowest percentage in January (63.1%) of PV / T.

CHAPTER 3
SOLAR ENERGY POTENTIAL

3.1 Type of Energy Sources

3.1.1 Non-Renewable Energy

Over millions of years, due to geological processes, non-renewable resources have been formed. Non-renewable resources come from sources that will not be renewed. It indicates that using non-renewable energy is faster and more reliable than using renewable energy. Non-renewable energy includes four main types: fossil fuels, oil, and natural gas (Foster et al., 2010).

Nuclear Energy

Nuclear energy is one of the world's common methods to produce electricity and produce 20% of its total electricity production. Nuclear energy diffuses upon nuclear fission. It uses the split atoms to heat water into steam and generate electricity by converting nuclear energy turbines. Nuclear energy has many risks to the environment because it produces radioactive materials, and radioactive waste causes serious diseases, especially blood and cancer diseases see Figure 3.1.

Coal

Coal is the world's most widely used fossil fuel for the energy used to produce electricity. The energy was stored by plants in forests over hundreds of millions of years, and this stored energy contained coal production. 93% of escaped coal is used to produce electricity in the United States. The combustion of coal produces a large amount of CO_2 emissions as shown in Figure 3.2.

Petroleum

Petroleum energy often consists of oil or petroleum and is a fossil fuel. Petroleum is known as a toxic liquid and has flammability in an underground geological formation. The toxic liquid produced from petroleum energy production threatens human health and causes human leukemia as shown in Figure 3.3.

Natural gas

Natural gas consists of a source of methane gas and is a non-renewable hydrocarbon material shown in Figure 3.4. Natural gas is one of the most common energy production types for generating electricity and is used in the commercial field in the plastic industry and for organic chemical purposes. The environment is greatly affected by the natural gas method's energy production because it produces greenhouse gas emissions.

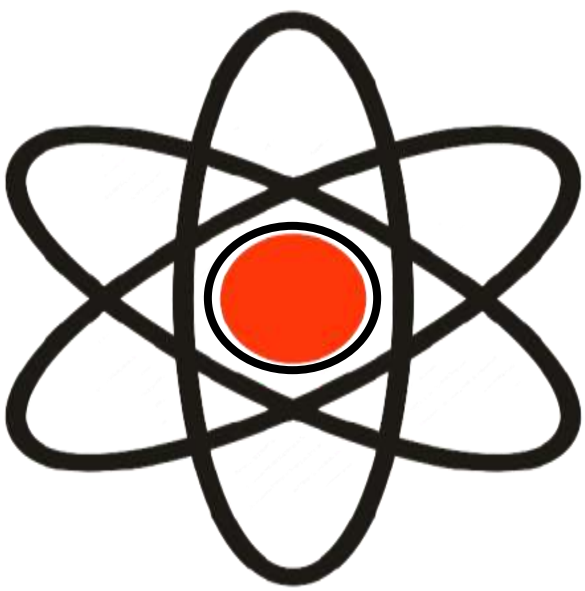

Figure 3.1: Nuclear energy

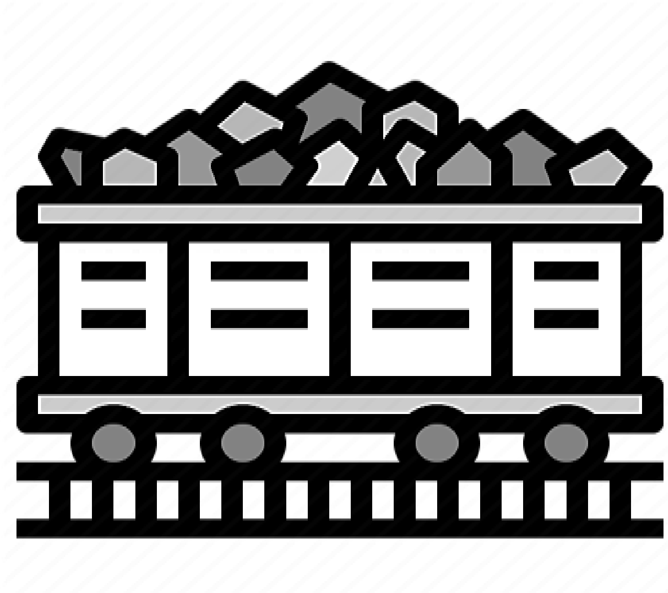

Figure 3.2: Coal

Figure 3.3: Petroleum

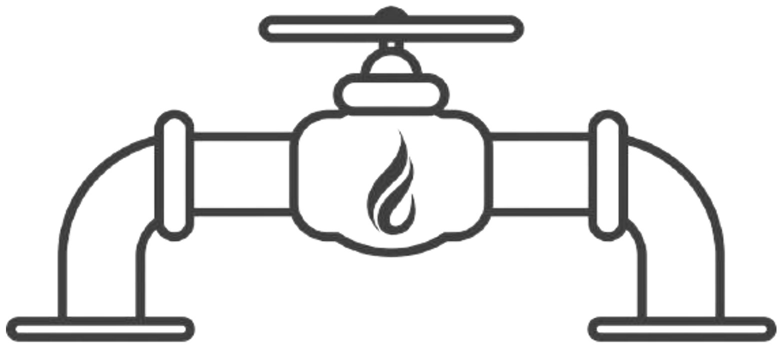

Figure 3.4: Natural Gas

3.1.2 Renewable Energy

Renewable energy sources are often considered clean and non-consuming sources and come from continuously renewable natural sources. The most common renewable energy sources are sun, wind, hydroelectric, and storms, and these sources are free from greenhouse gas emissions and other emissions (Kang et al., 2019).

As shown in Figure 3.5, renewable energy is depleted and inexhaustible. As its name indicates, it is constantly renewed, and whenever it approaches completion appears again because its source is natural resources (Nayeripour et al., 2011).

Renewable energy has very important characteristics that help the development of its use and dependence on it, which are (Toklu, 2013):

1. It is clean energy that is environmentally friendly.
2. It does not release harmful gases such as CO2.
3. Saving reduces cost.
4. Developing new energy market policies.
5. It does not play a major role in the degree of temperature.

Renewable energy technology has a host of advantages that make it a reliable and distinct source of energy.

1. Renewable energy is clean energy-friendly with the environment.
2. Renewable energy is permanently present and renewable again.
3. The technologies used for renewable energy are easy and very simple mechanisms.
4. Renewable energy is a very important factor in the social environment and the development of many fields.
5. It is very economical.
6. The waste that remains from the impact of energy produced using renewable energy technologies is free of greenhouse gas and thermal emissions and Prevents harmful acid precipitation.
7. On the agricultural side, it is free from chemical pollutants, and this helps increase agricultural production.
8. It uses uncomplicated technology and can be developed in developing countries locally.

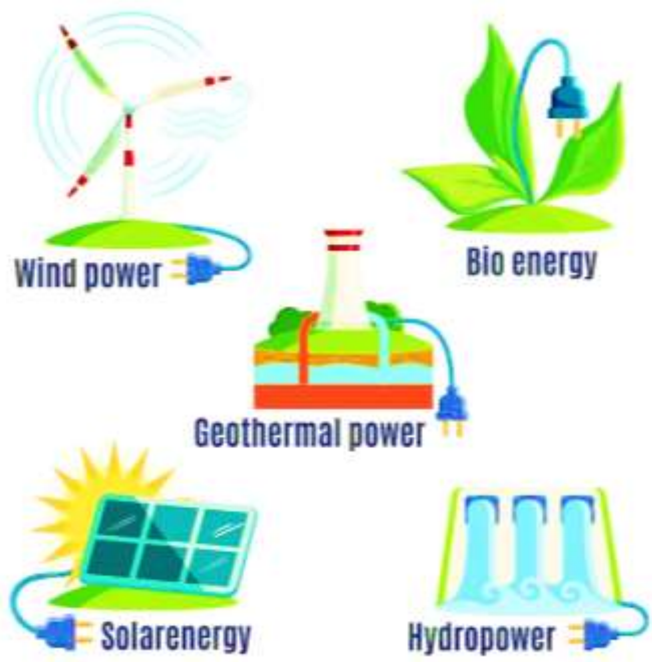

Figure 3.5: Renewable Energy Sources

3.2 Solar Energy

The Sun, or the origin of the solar system, is measured at 26,000 light-years to be the nearest star to earth. It is estimated that the star is 4.5 billion years old. For the solar system's equilibrium, the immense gravity of the Sun is responsible for fixing all elements of the solar system from huge planets too small portions of their orbit.

Solar energy takes away from the sun's rays and is called the sun's energy emitted. Solar energy is mainly made up of the heat of sunlight ablution. This energy is considered the energy of great importance for the earth and the organisms on the earth's surface. In general, the amount of solar energy produced exceeds the large requirements for energy production in the world. If this energy is used properly, the required technologies with their capacity can meet all future energy needs.

All life on Earth is supported by the sun or the rays of the sun. The sun's energy can be used in many diverse fields, including commercial, home environment, and other industries. Sunlight has a significant role in hydropower, wind energy, and the agricultural field, transmitting light to plants to produce food and biomass. Solar energy is responsible for a variety of renewable energy and is considered the most important energy source.

Scientific researchers are constantly and increasingly interested in renewable energy sources due to the world's growing concerns that stem from climate change. Renewable energy has the capabilities and distinction of continuously replenishing resources, not depleting them.

In general, by transforming the energy inherent in sunlight, this energy is the generation of heat. This energy attracts and transports the sun's heat and photovoltaic cells into a water cycle to supply hot water or heating for homes. Many methods can be categorized into three major groups for the effective use of solar energy: thermal applications, the processing of electricity and chemical processes, and the most commonly used applications in the field of water heating. Photovoltaic systems and solar thermal solutions, focused on transforming sunlight into energy using solar panels, are currently producing electricity (see Figure 3.6). The photovoltaic cells' ability to transform solar energy directly into electricity and ease of use make it available, especially in developing countries where large generators do not exist.

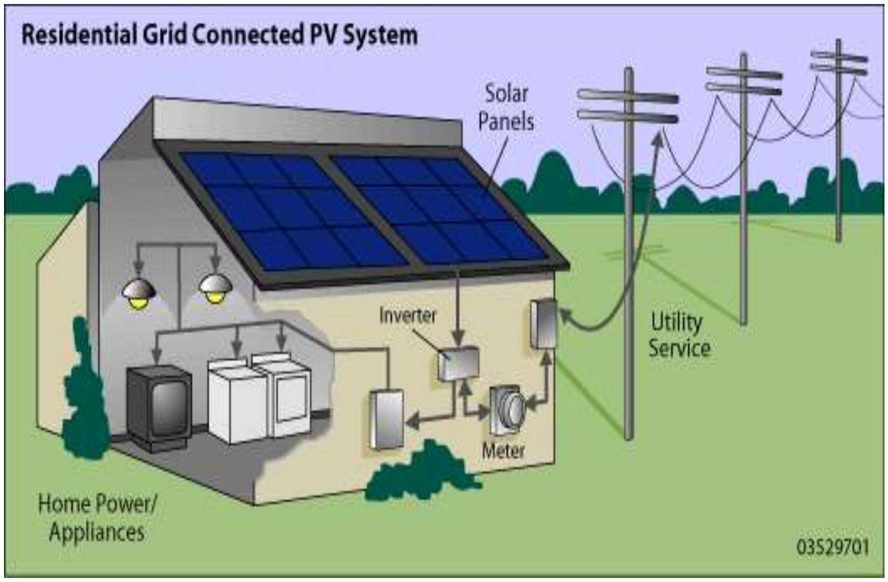

Figure 3.6: Residential Grid-Connected PV System (Kassem et al., 2020)

3.2.1 Advantage of Solar Energy

The most available and free electricity source is solar energy, and humans use it in all of their everyday activities.

1. Using solar energy helps reduce costs in economic terms for home and real estate owners.
2. The development of the renewable energy sector, especially solar energy, can provide many companies jobs, especially in this field.
3. Solar power stations are clean and environmentally friendly compared to fossil fuel stations due to the low percentage of chemical emissions that harm the environment.
4. It can solve climate changes at different times of the year by storing the increased energy and distributing it when there is not enough sunlight.
5. It can be used as a substitute for fossil fuels for cars and eliminates the need for oil.
6. Solar energy cannot be depleted and is considered sustainable energy that can be found at all times and has the potential for development and innovation compared to other sources of energy.

3.2.2 Disadvantage of Solar Energy

The fact that solar energy is one of the most critical energy sources is undeniable. It is not without its drawbacks, though. The key downsides to solar energy are the following:

1. The great expense of generating vast quantities of electricity from solar panels.
2. The recycling of solar panels is a source of water contamination since this detrimental impact can be avoided if the manufacturing of solar panels requires organic materials.
3. Relying on overnight battery systems and periods when panels are unable to consume sufficiently solar radiation.
4. It takes time for solar energy systems to become mainstream and generally embraced as an alternative to generating energy.

3.2.3 Solar Energy Use

Through photovoltaic conversion and thermal conversion of solar energy, solar energy can be transformed into electric and thermal energy as follows (Foster, 2010):

Solar thermal uses

- Solar water heating

It is an interconnected device composed of multiple parts used to absorb and transform the solar rays falling on them into heat energy to be used during the hours of daylight to heat water where hot water is collected for use during the day in a heated tank, as seen in Figure 3.7.

- Solar swimming pool heating

To heat the pool water, solar water heaters may also be used (Figure 3.8). For this purpose, inexpensive unclassed solar collectors, which are typically made of plastic materials specially engineered for this purpose, are used to heat the pool water. Solar collectors heat pool water to temperatures just above average temperature.

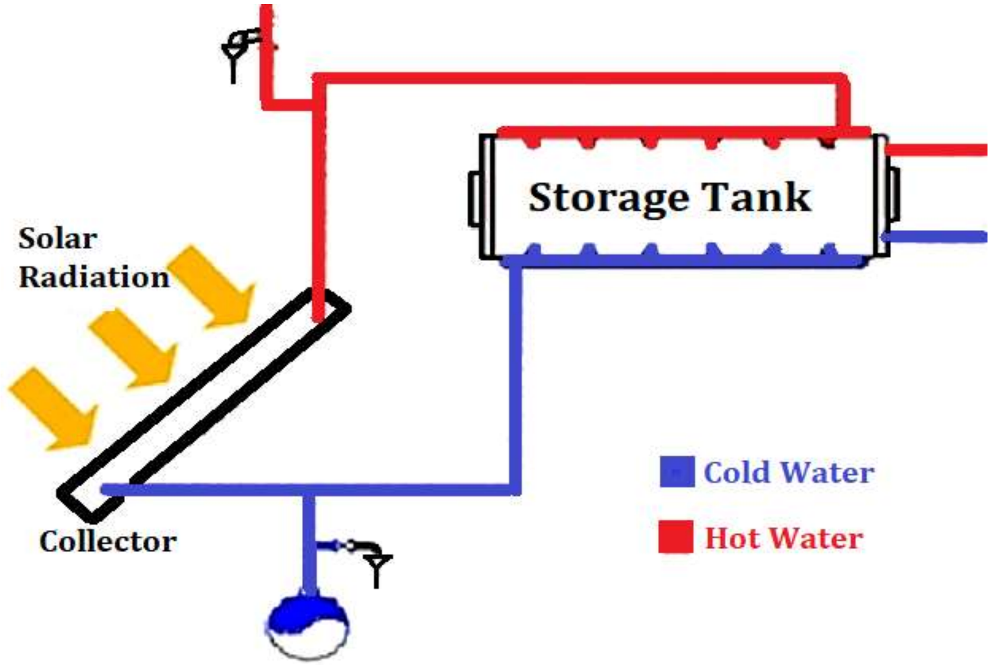

Figure 3.7: Solar water heating

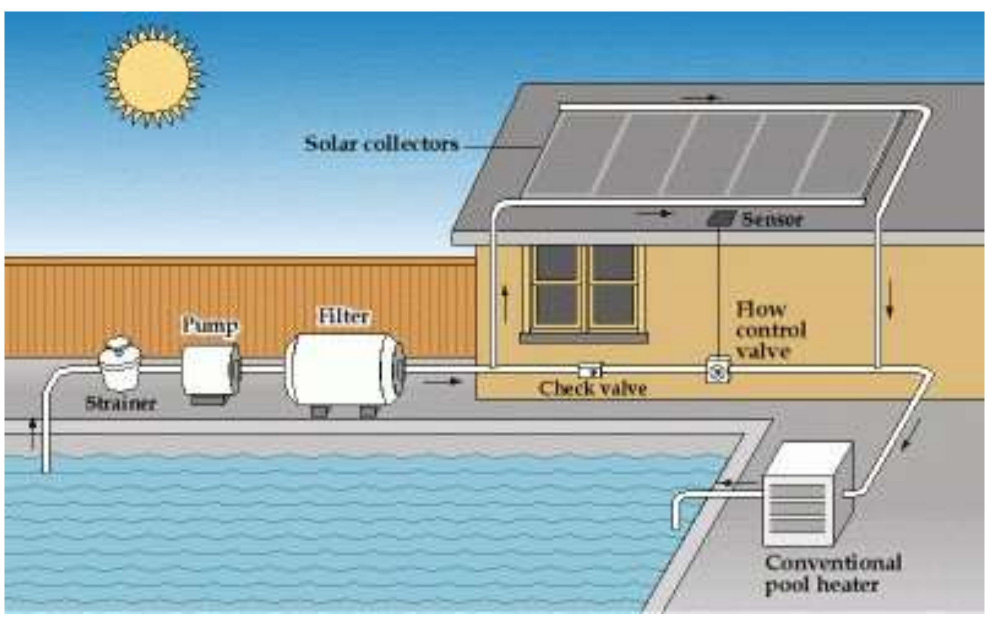

Figure 3.8: Solar swimming pool heating (Foster, 2010)

- Sewage Treatment

Using photodegradation, solar energy is often used to extract pollutants from polluted water, as shown in Figure 3.9.

- Solar cooking

The solar cooker is a device that heats, dries, and pasteurizes using sunlight. Figure 3.10, for instance, displays the parabolic solar cooker.

Figure 3.9: Solar Farm to a wastewater treatment plant (Foster, 2010)

Figure 3.10: Parabolic solar cooker (Foster, 2010)

Use of solar energy to generate electricity

One of the energy carriers which can be used for several applications is electricity. Via photovoltaic transition, solar energy can be transformed into electrical energy. It is planned to use photovoltaic solar cells to directly transform solar or light radiation into electrical energy, as shown in Figure 3.11.

Figure 3.11: Use of solar energy to generate electricity

2.2.4 Solar panels work (Photovoltaic)

As the interest in renewable energies in general and solar energy, in particular, is rising, efforts have been made to provide solar energy technology with an energy level comparable to or similar to the amount of energy expended. The transformation of buildings from energy-consuming plants into efficient buildings, which rely on the sun as an economical source of energy, has become widespread and widely used even in areas with high solar radiation levels or areas with limited sunshine (Chel et al., 2018).

The solar system for producing electricity consists of the following four fundamental elements (see Figure 3.12):

- PV photovoltaic
- Charger controllers
- Invertors

- Batteries

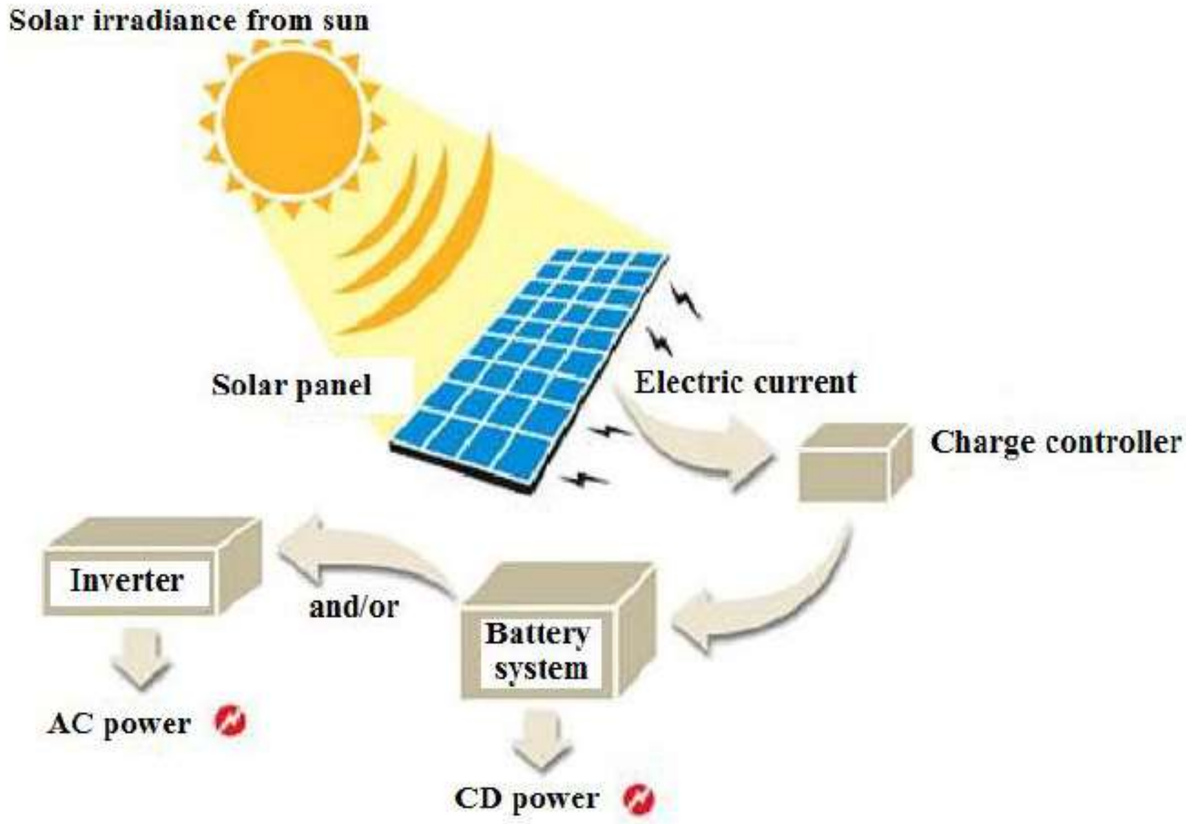

Figure 3.12: Elements of the PV system (Chel et al., 2018)

PV photovoltaic

That is the visible component of the solar panel mounted on the building's roof used for energy generation. Figure 3.13 shows the elements of solar panels. The solar panel collects solar cells that generate DC electricity that can be used to power some appliances or deposited in recharged batteries that can be used more than once. Watt is the unit of the determined intensity of the cells.

The solar cell's key feature, the solar cell, illustrates how solar panels work.

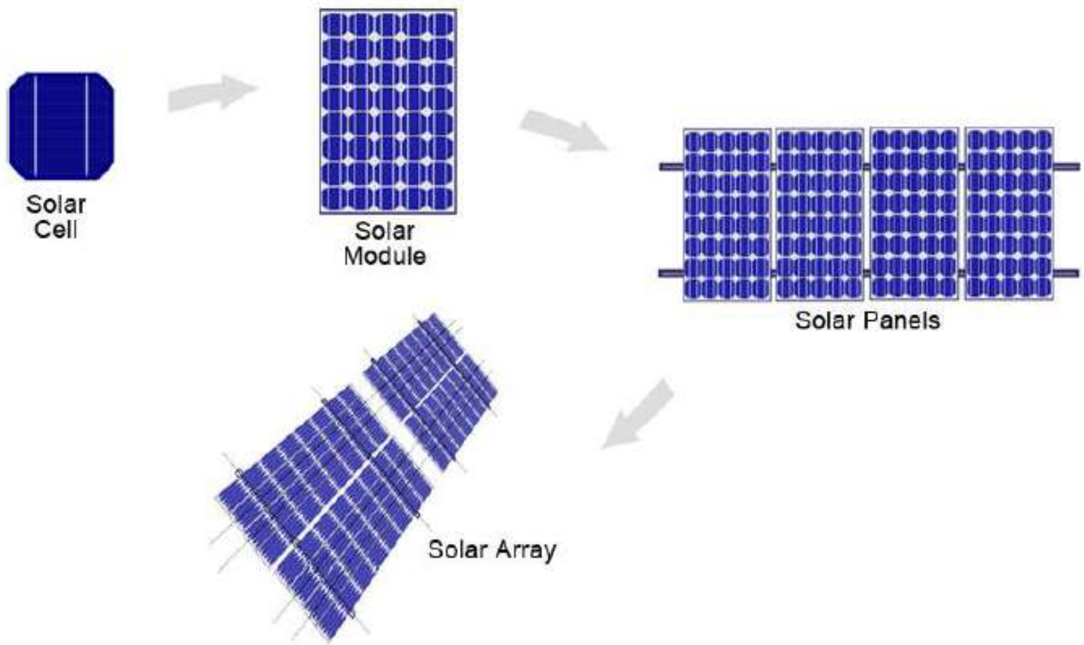

Figure 3.13: Components of PV panels

PV cell

It is the solar system's primary feature, which is the smallest portion of it. By translating radiation energy into electrical energy, they respond to direct and indirect solar radiation. Solar panels take advantage of sunlight, which stimulates electrons to create a current inside a cell. The photovoltaic cell consists of semiconductors, mostly packed onto a specially treated chip to create an electric field, positive on one end and negative on the other end (see Figure 3.14). Electrons are accelerated to a higher energy state to produce electricity, and electrons are stored when electrical conductors' electric current is attached to the negative and positive ends. The electrical energy that occurs is DC energy, and the energy is deposited in separate size batteries so that it can be used after the sun's demise (Marsh, 2019).

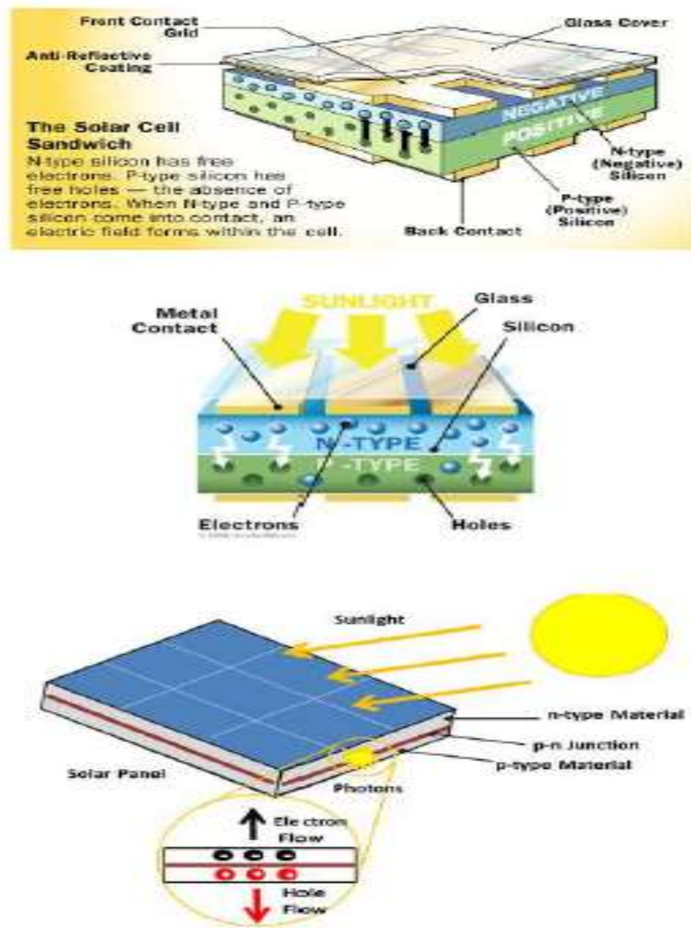

Figure 3.14: PV cell working principle

Solar cells installed under the sun directly absorb. This is the beginning of converting the sun's rays and dissolving them into electricity for human use in many purposes and fields. Thus they act as an alternative to regular generators. When the sun shines contain many regular solar cells, the saturated conductive materials are present in the solar cells. The majority of them are silicon. When the cells receive solar energy, the semiconductor material or silicon material accumulates. The energy produces electricity when the electronics are launched. The direct current method produces electricity (and It turns out like chemically produced electricity), then it is converted into direct current electricity. Figure 3.15 shows alternating current electricity through a solution called an (Inverter).

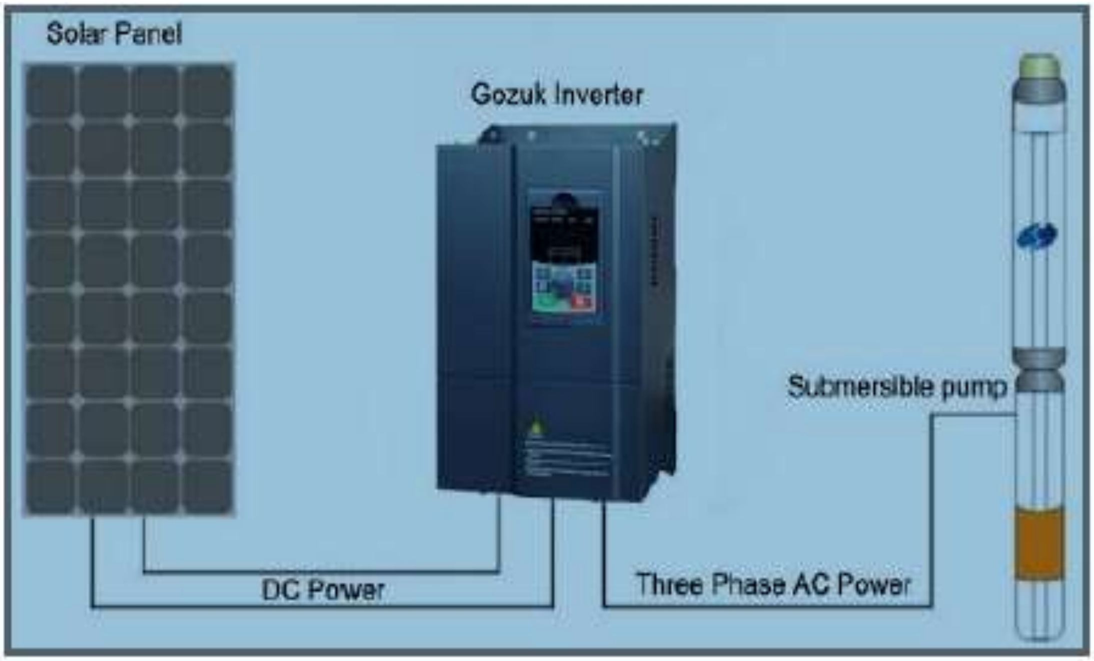

Figure 3.15: Inverter (Chel et al., 2018)

Types of solar cells

While all solar panels function in the same manner, there are many types of solar panels on the market, ranging from several variants to be found to select the best type of site to the most common types of solar panels (Green-Match, 2015):

- Mono-crystalline, the mono-crystalline panels (Figure 3.16) are distinguished by the purity of the silicon crystals from which the cells are formed. In addition to high longevity, the panels need to have the same amount of energy as other types and still have the capacity to operate effectively in low light.
- Poly-crystalline is referred to as polycrystalline solar panels (Figure 3.17), which differs from the monotype in the shape that the cells are compact squares, and their performance is medium, contributing to the need for more of them to produce the same energy, which is less costly than the high-life monotype.

- Thin film, the third form of a thin-film solar panel, is named (Figure 3.18). This type is Flexible and easy to mount. The short lifespan of the same volume of electrical energy can be derived from other organisms.

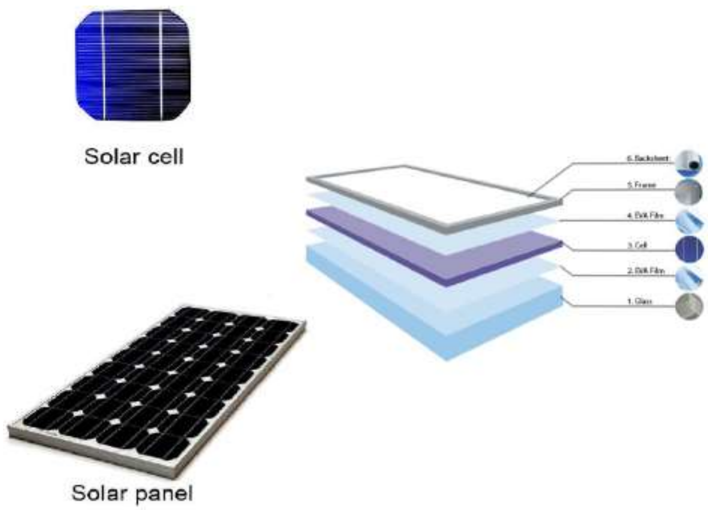

Figure 3.16: Monocrystalline solar panels

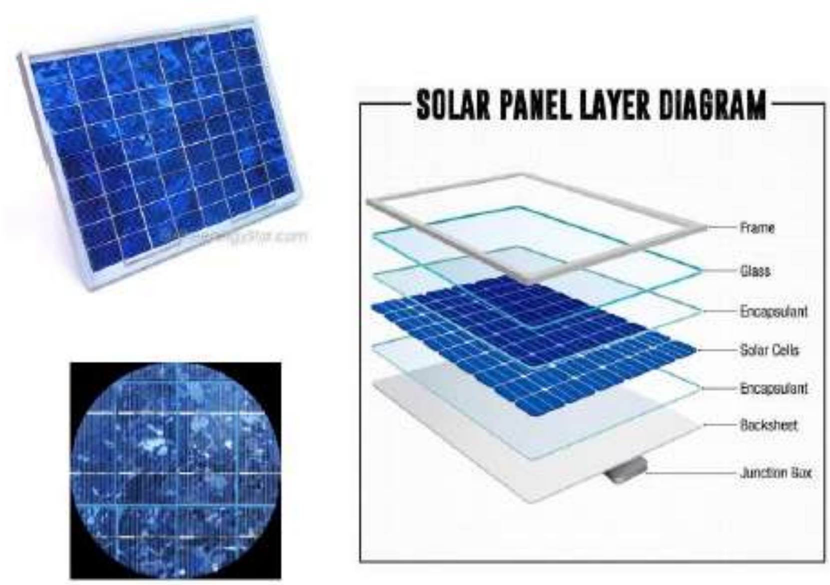

Figure3.17: Poly-crystalline solar panel

Figure 3.18: Thin-film solar panel (Green-Match, 2015)

3.3 Factors Affect the Solar Radiation Values

Solar radiation is the real fuel for all solar energy devices. Still, the performance of electricity generation solar panels and hot water generating thermal systems relies on solar radiation availability and density. Radiation is relatively stable above the atmosphere, but the amount of radiation touching the Earth's surface differs somewhat differently. There are several causes, but the most important factors influencing the decrease in solar radiation quality and thus the productivity performance of solar panels are:

Geographical presentation

Because of the spherical Planet, as we come closer to the equator, the rays landing on the surface are more concentrated and heavier because it is the fastest radiation path to hit the perpendicular surface. Thus less radiation is wasted due to contact with the atmosphere. Let's move away from the north or south of the equator. The fusion time between radiation and the envelope will increase, creating dispersion, thereby weakening radiation intensity and power.

Cloud coverage

Compared to solar radiation falling on the surface, clouds are a significant factor because they reflect and absorb a large part of the sun's rays. Thus, if there are two positions at one latitude, the difference in incident radiation may be significant depending on seasonal cloud coverage. Clouds, on average, absorb and reflect 20% of the total rays coming from the sun.

The suspended particles

Typically, dust particles or pollutants of human industrial activity and emissions are suspended from the Earth's atmosphere. The quantity and concentration of these dust particles vary depending on the location and time of year. The value of solar radiation is that it filters radiation and decreases it. Although this affects solar panels' efficiency, the performance of the concentrated radiation used in giant solar systems is more harmful.

Height

The distance covered by radiation is shorter than the Planet's height above sea level when it hits the Earth's surface. Radiation leakage rates are thus minimized, resulting in increased efficiency of all forms of solar generators.

Shadow and angle

The position of construction and installation of solar panels is one of the most critical things to remember if we want to consume the highest amount of incident radiation, given that any shadows on solar panels or concentrates can be removed from adjacent buildings or others during the daytime. For panels that meet the sun as often as possible during the day, an angle should be fixed, and sometimes the optimal angle for longitude, latitude, and annual seasons depends on your position.

CHAPTER 4
MATERIAL AND METHOD

4.1 Description of Methodology

An economic analysis of the solar energy potential was provided in four regions in Dohuk, Iraq. To provide this requirement and realize the potential of solar energy in the selected regions, NASA data was used. The PV systems and the saving methods for their use are discussed. The procedure for analysis in this study is shown in Figure 4.1.

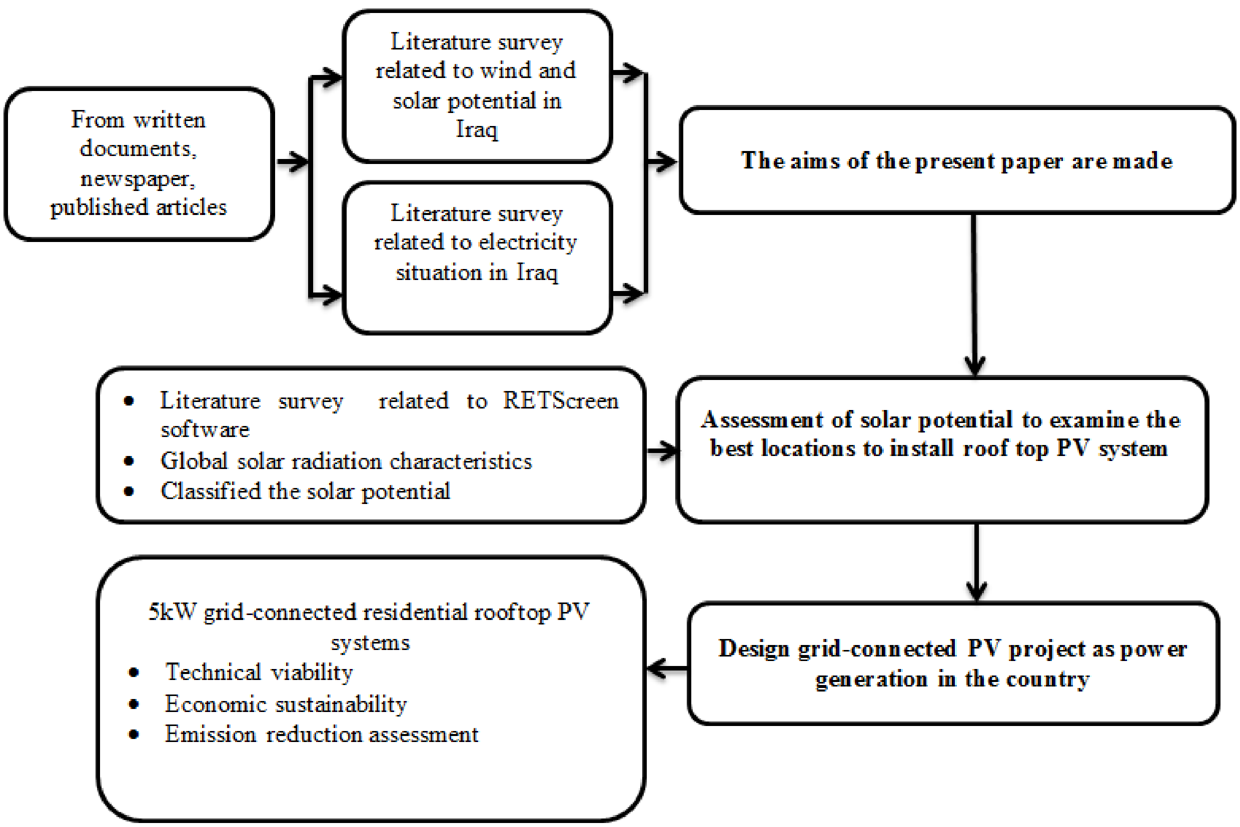

Figure 4.1: Schematic explanation for the proposed methodology

4.2 Solar Radiation Data

Most satellite data can determine solar energy sources' evaluation, and we can see it in many studies.

For instance, (Obeng et al. 2020) assessed the solar potential using NASA SSE solar irradiation at UENR (the University of Energy and Natural Resources) Nsoatre Campus. The solar potential was measured at six different locations in Nigeria using the NASA database (Owolabi et al., 2019). Besides, to demonstrate the accuracy of satellite databases, numerous studies have compared measured global solar radiation with estimated data (satellite databases). The actual monthly global solar radiation was compared (with the satellite imagery database for various regions in northern Cyprus (Kassem et al. 2020). The results indicated that the Global Solar Radiation (GSR) estimated data was close to the actual data. The solar potential of the Ghardaïa zone, Algeria, using measured solar radiation, the NASA SSE (Surface Meteorology and Solar Energy Service) model, and the Solar-Med-Atlas were assessed (Gairaa et al., 2013). The findings revealed that the data from the calculation are following the predicted database. (Belkilani et al. 2018) analyzed and correlated with the satellite radiation databases the real outcome of the monthly GSR for three sites in Tunisia. The findings showed that the estimated data showed a strong correlation with the real GSR information. As a result, NASA's average monthly ratio was used to determine solar energy's capacity in the regions chosen.

4.3 Design of the PV Power System

The major parameters that are considered for the design of a PV power plant are, according to (Kassem et al. 2020; Owolabi et al. 2019):

Power generating factor:

$$PGE = \frac{Solar\ irradiance\ \times\ Sunshine\ hours}{Standard\ test\ condition\ irradiance} \tag{4.1}$$

Solar PV energy required:

$$The\ energy\ required\ from\ PV\ modules = Peak\ energy\ requirement \times Energy\ lost\ in\ the\ system. \quad (4.2)$$

PV module sizing:

$$\text{Total Watt peak rating} = \frac{Solar\ PV\ energy\ required}{panel\ generation\ factor} \quad (4.3)$$

$$\text{PV module size} = \frac{Total\ Watt\ peak\ rating}{PV\ output\ power\ rating} \quad (4.4)$$

Inverter sizing:

$$Inverter\ size = Peak\ energy\ requirement \times Factor\ of\ safety. \quad (4.5)$$

4.4 Grid-Connected 5kW Residential Rooftop PV System

The PV technologies were considered mono-crystalline silicon (mono-Si) for the proposed 5 kW grid-connected rooftop. Seventeen modules of the selected modules (mono-Si-CS6X-300M) were needed to create the 5 kW grid-connected residential/household rooftop in the selected locations. The Growatt 5500MTL-S Dual MPPT 6KW Solar Inverter with a total power of 6000W has been used for the planned PV system. The definition of a chosen inverter is shown in Table 4.1, and the specification of the chosen inverter is shown in Table 4.2.

Table 4.1: Technical specification of the Photovoltaic (PV) modules.

PV Module Technology	Mono-si
Manufacture	Canadian Solar
Model	mono-Si-CS6X-300M
Nominal power (W)	300
Open-circuit voltage (V)	45
Short-circuit current (A)	8.74
The voltage at the point of maximum power (V)	36.5
Current at point of maximum power (A)	8.22
Module area (m2)	1.919
Efficiency (%)	15.63
Warranty (Year)	25
Cost (USD/Wdc)	0.83

Table 4.2: Technical specification of the selected inverter.

PV Module Technology	Value
Rated power (W)	6000
Min PPT Voltage (V)	100
Max PPT Voltage (V)	550
DC startup voltage (V)	100
DC shutdown voltage (V)	80
Max input voltage (V)	550
Max DC power (W)	6500
Max AC power (W)	5000
Max DC current (A)	30
Warranty (year)	10
Efficiency (%)	97.9
Cost (USD)	550

4.5. Economic Analysis

Physicists, researchers, and engineers have used different modeling approaches to approximate the annual and monthly energy output and the installed solar PV system's power factor. Several science researchers have used RETScreen and other related software, such as HOMER, to evaluate the technological and environmental feasibility of solar PV technologies worldwide.
To evaluate the techno-economic and environmental dimensions of the 5 kW grid-connected rooftop solar PV system, RETScreen Expert software is used to compare its power across selected regions. RETScreen software is a valuable instrument to assess and determine the viability of a clean energy device linked to the grid. RETScreen tools will predict annual and monthly energy production, power factors, and other important economic metrics based on input data.
RETScreen Specialist program was utilized to assess the project's economic feasibility measures. Described as an equation, the following indicators are given below:

Net present value (NPV):

$$(NPV) = \sum_{N=0}^{N} \frac{C_n}{(1+r)^n} \tag{4.6}$$

Levelized cost of energy (LCOE):

$$LCOE = \frac{sum\ of\ cost\ over\ life\ time}{s\ o\ f\ electricity\ generated\ over\ the\ li\ f\ etime} \tag{4.7}$$

The internal rate of return (IRR):

$$(IRR) = \sum_{N=0}^{N} \frac{C_n}{(1+IRR)^n} \tag{4.8}$$

Simple payback (SP):

$$SP = \frac{C - C1}{(C_{ener} + C_{capa} + C_{RE} + C_{GHG}) - (C_{0\&M} + C_{fuel})} \tag{4.9}$$

Equity payback (EP):

$$(EP) = \sum_{N=0}^{N} C_n \tag{4.10}$$

The annual life cycle savings (ALCS):

$$(ALCS) = \frac{NVP}{\frac{2}{r}\left(\frac{1}{(1+r)^N}\right)} \tag{4.11}$$

GHG emission reduction cost (GHGERC):

$$GRC = \frac{ALCS}{\Delta_{GHG}} \tag{4.12}$$

Benefit-Cost ratio (B-C):

$$B - C = \frac{(NPV) + (1 - f_d)}{(1 - f_d)^C} \tag{4.13}$$

Capacity factor (CF):

$$CF = \frac{P_{out}}{9 \times 8760} \tag{4.14}$$

Pout is the main energy produced annually, p is the installed capacity of the energy, N is the sustainable life of the project in years, Cn is the cash flow in n year after tax, r is the full rate of deduction, C is the initial cost of the project, fd comes as the debt ratio, B is the total interest for the whole project, IG is grants and incentives, Cener energy income per year, Ccapa is annual income, CRE renewable energy produced every year, CGHG is the thermal gas reduction, RE production credit income. Co&M is the annual cost of service and maintenance borne by Cfuel, the renewable energy initiative. The annual fuel cost is negligible for green ventures, and DGHG is the annual reduction in GHG emissions.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 Solar Energy Potential

Global horizontal irradiation (GHI) is an important parameter for assessing flat-plate photovoltaic energy generation, solar power concentration, and photovoltaic concentration systems. Air temperature (AT) is one of the most essential parameters for PV system efficiency predictions.

5.1.1 Global Solar Characteristics

The average monthly GHI for regions Aqrah, Duhok, Simele and Zakho are shown in Figure 5.1, respectively. The monthly GHI values are found to be within the range of 62.179-248.088 kWh/m2. Determination of the monthly rate of AT for all regions, shown in Figure 5.2. It was also observed that in the Simele and Duhok regions, the highest and lowest AT values were obtained with values of 33.47 (Jul) and 2.81 ° C (January), respectively.

Additionally, for all regions, Table 5.1 shows the annual GHI and AT. The maximum annual GHI with a value of 1847,788 kWh/m2 was found to have been obtained in Simele and Duhok. The lowest GHI values were reported with a value of 1783.222 kWh/m2.

Additionally, it is noted that the maximum and minimum air temperature values in Simele and Duhok were reported at 19.2 and 16.4 °C, respectively.

Table 5.1: Annual mean GHI and AT for all selected regions.

Parameters	Duhok	Aqrah	Simele	Zakho
GHI (kWh/m2)	1783.222	1803.248	1847.788	1808.914
AT (°C)	16.425	18.464	19.260	19.166

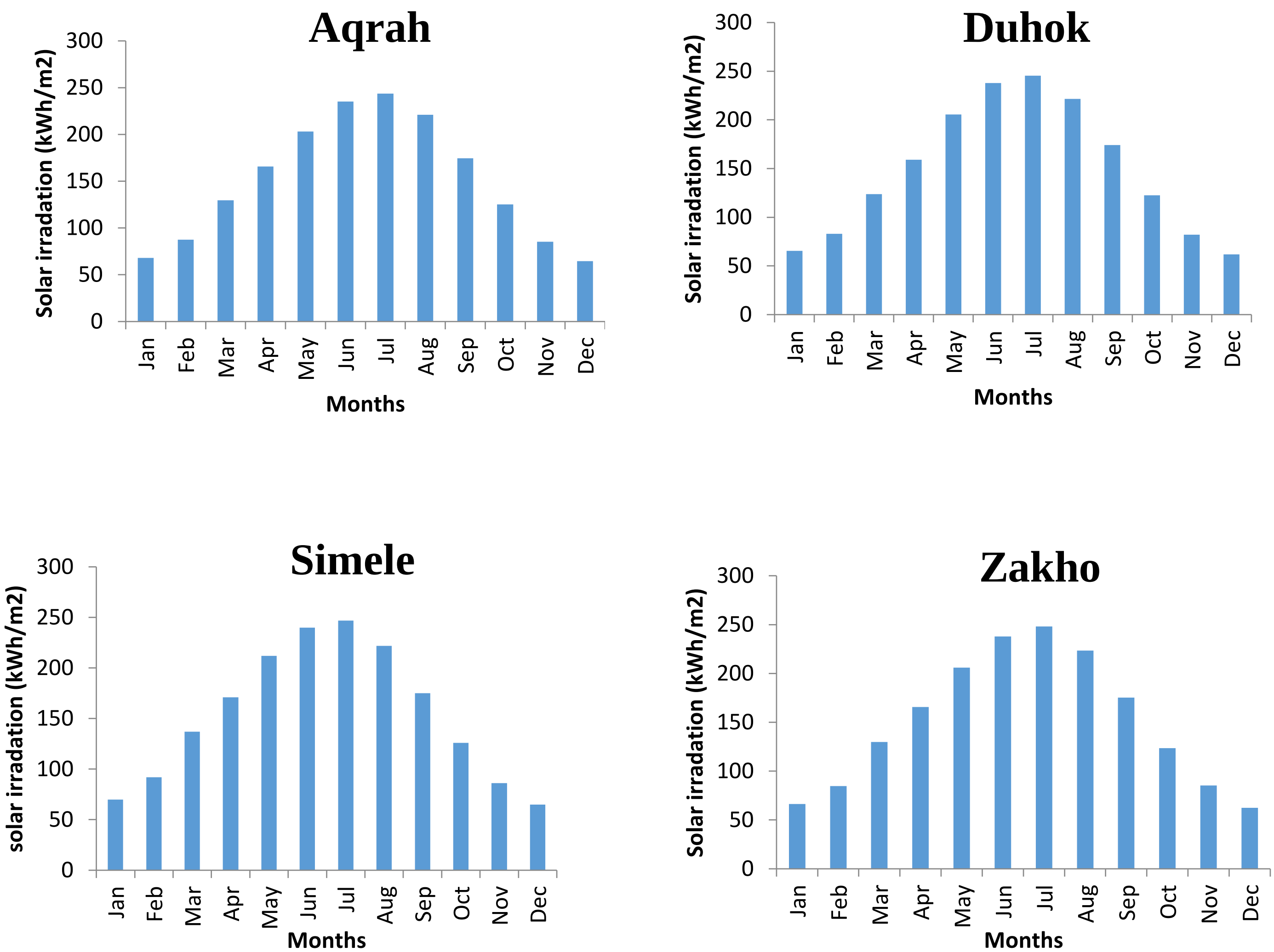

Figure 5.1: Average of monthly GHI for all regions

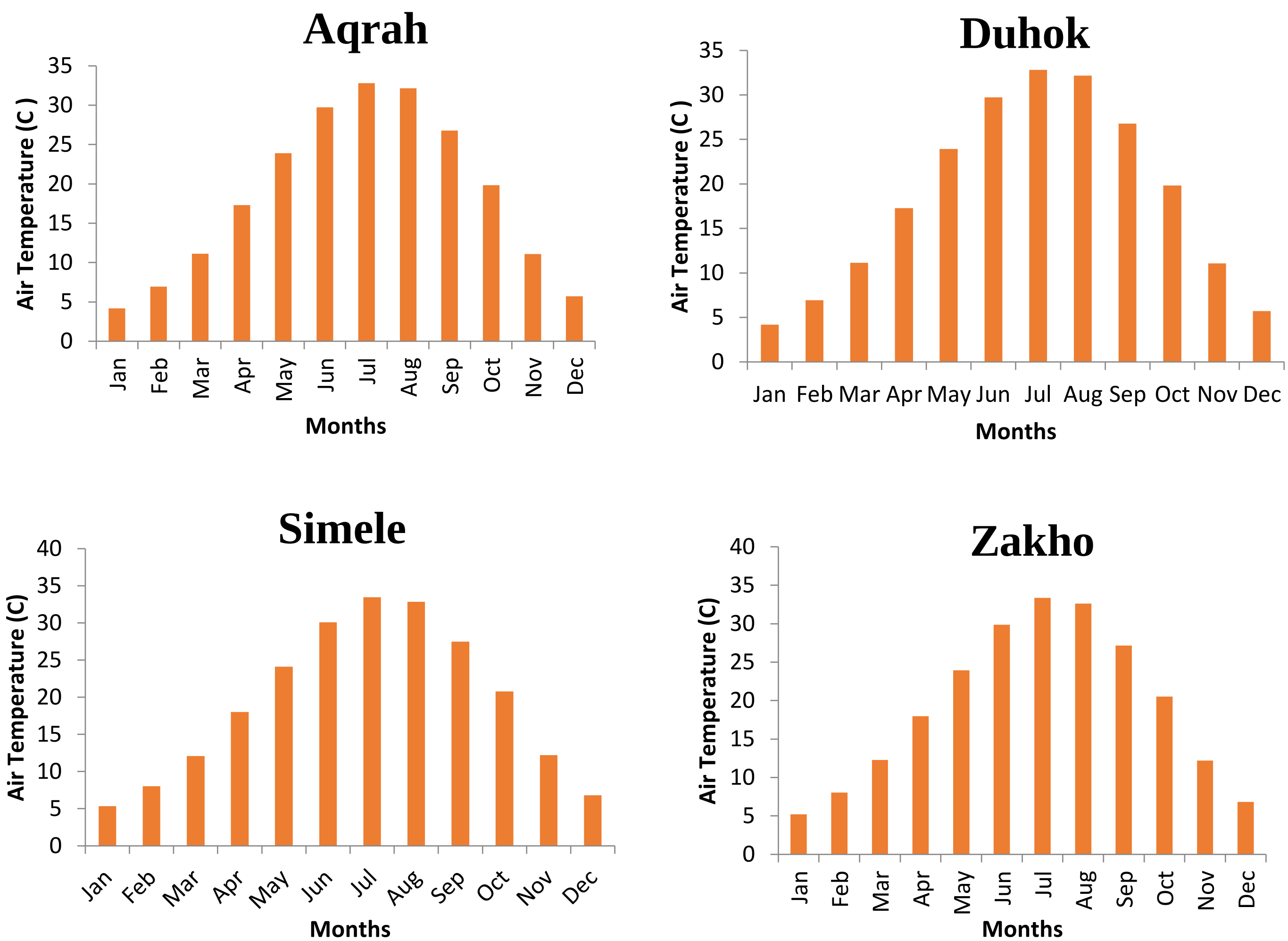

Figure 5.2: Average of monthly AT for all regions

5.1.2. Solar Potential Classification

As described above, GHI has been used to assess the solar energy potential in the region. The description of solar energy for the chosen area based on annual global horizontal irradiation is seen in Table 5.3, based on the solar capacity groups (Table 5.2). It should be remembered that the areas chosen have a high solar capacity and have been rated as good or excellent future grades. It was also found that the Simele location solar resource was graded as excellent (class 5). Consequently, due to the high importance of global solar radiation (GHI), it is assumed that Aqrah is the most suitable area for installing large-scale photovoltaic systems. Thus, it should be noted that all selected regions are suitable for installing PV/flat-plate and CSP systems.

Table 5.2: Solar potential classification based on annual GHI

Class	GHI (kWh/m2)
1 (Poor)	<1191.8
2 (marginal)	1191.8–1419.7
3 (fair)	1419.7–1641.8
4 (good)	1641.8–1843.8
5 (excellent)	1641.8–2035.9
6 (outstanding)	2035.9–2221.8
7 (superb)	>2221.8

Table 5.3: HGI Classification based on NASA Data

Class	GHI (kWh/m2)
Duhok	Good
Aqrah	Excellent
Simele	Good
Zakho	Good

5.1.3 Assessment of PV Systems Performance

A fixed-tilt system for a rooftop solar PV system in all selected cities has been suggested for the proposed system. The PVGIS modeling method was used to find the optimal angles for all chosen positions regarding the slope angle and the azimuth angle. For all the selected regions, Table 5.4 lists the optimal angle for the future PV installation device. RETScreen software was used to examine a 5 kW PV device's economic viability linked to the grid in the chosen locations. For all the selected regions, Table 5.4 lists the optimal angle for the future PV installation device. RETScreen software was used to examine a 5 kW PV system's economic feasibility for the grid-connected in the chosen locations. The annual electricity generation and capacity factor from the proposed system with PV technology are shown in Figure 5.3 and Figure 5.4, respectively. At Aqrah, the maximum annual electricity production was reported, which is 7877.0869 kWh, and at Duhok, the lowest 7737.1227 kWh was recorded. Moreover, it was noted that the capacity factor (CF) values are within the range of (17.3183-17.6316 %), so these values suggest that the regions selected are suitable for developing PV projects.

Table 5.4: Optimum angles for the PV system for all selected regions

Parameters	**Duhok**	**Aqrah**	**Simele**	**Zakho**
Slope angle (°)	-6	-4	-3	-5
Azimuth angle (°)	31	32	32	33

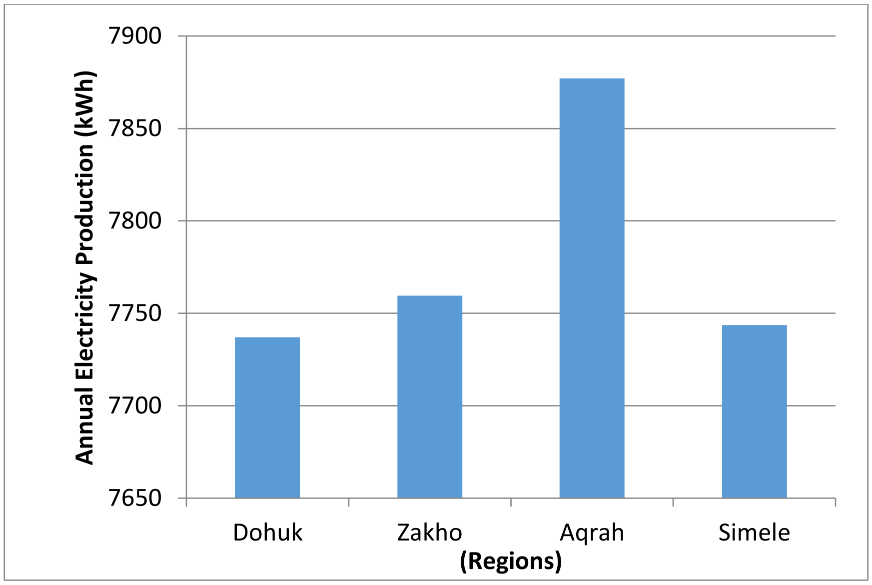

Figure 5.3: Annual electricity generation for all selected regions

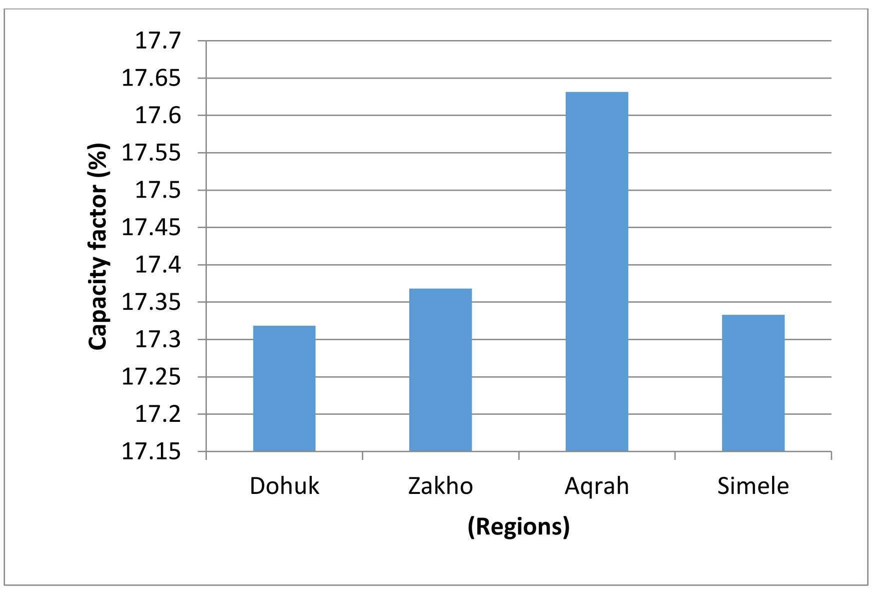

Figure 5.4: Capacity factor for all selected regions

5.1.4. Simulation Results of Financial and Emission Reduction Analysis

An economic analysis is a fundamental analysis to understand whether the proposal is commercially feasible and sustainable. The analysis of the economic feasibility of the effects of PV power plants teaches consumers and policymakers. In general, the critical economic viability criteria for calculating the PV project are NPV and the payback period. Thus, the study's findings suggest that NPV values are flattering for all regions, as seen in Table 5.5.

The proposed photovoltaic project shows the most extended payback period in the Dohuk region of 6.7997 years, followed by the Simele region, whose project can import 6.7939 years Aqrah region has the shortest recovery period, which is 6.6789 years (see Figure 5.5). Moreover, Duhok has the highest equity payback of 3.5736, while Aqrah has the lowest equity payback of 3.5057, as seen in Figure 5.6. Moreover, it was observed that the region of Aqrah has the lowest electricity cost of 0.0267$/kWh, followed by the region of Zakho with an average value of 0.0271$/kWh. In contrast, the region of Duhok has the highest average electricity cost of 0.0328$/kWh, as seen in Table 5.5.

In this study, as seen in Figure 5.7, RETScreen software was used to approximate the gross annual reduction in GHG emissions for each of the four regions. The Aqrah region project has a maximum reduction in GHG emissions of 7.1156 tCO2. This is then preceded in the Zakho region by the program, with the smallest pollution reduction coming from the Duhok region project. Moreover, the percentage of the internal rate of return (Pre-tax Internal Rate of Return - equity) in all the selected areas, in addition to the (Pre-tax Internal Rate of Return - assets) were very suitable, especially in the Dohuk region, as shown in Table 5.5.

From a management perspective, the results indicated that the annual life cycle savings (year / $) in the Aqrah region were the highest, reaching 1368.552 (year / $), and the Duhok region had the lowest. It amounted to 1203.798 (year / $), as shown in Table 5.5. Moreover, Mono-si's PV technology provided a higher net present value (NPV) for Aqrah, with a cost of 34,213.8 ($), as shown in Figure 5.8. About the cost of reducing greenhouse gases ($/tCO2), a reduction in the cost of greenhouse gas emissions was shown in Table 5.5. Good results were shown in all the selected regions, especially in Aqrah and Zakho regions, and the reduced cost of greenhouse gas emissions was -192.33 ($/tCO2) and -191.882 ($/tCO2), respectively.

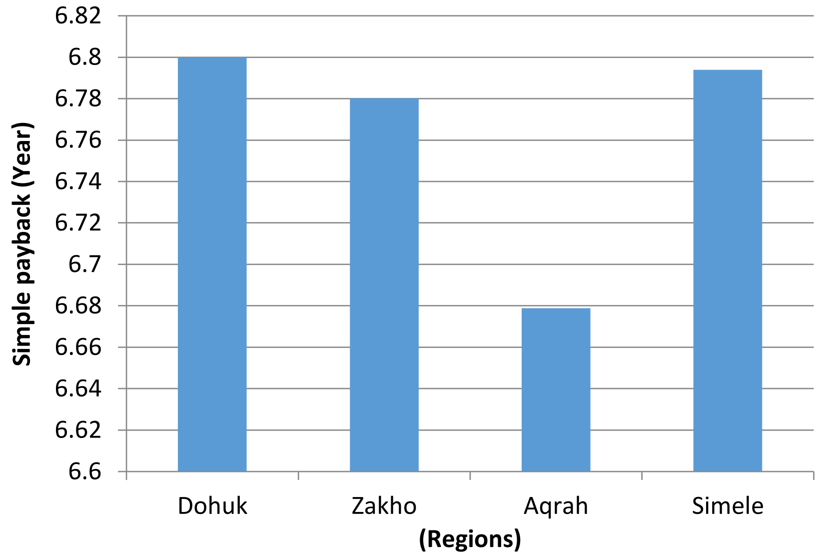

Figure 5.5: Simple payback (Year)

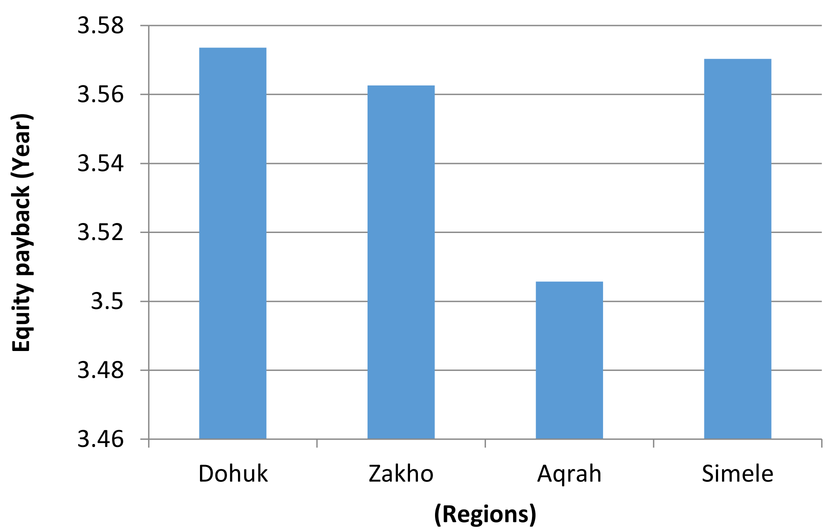

Figure 5.6: Equity payback (Year)

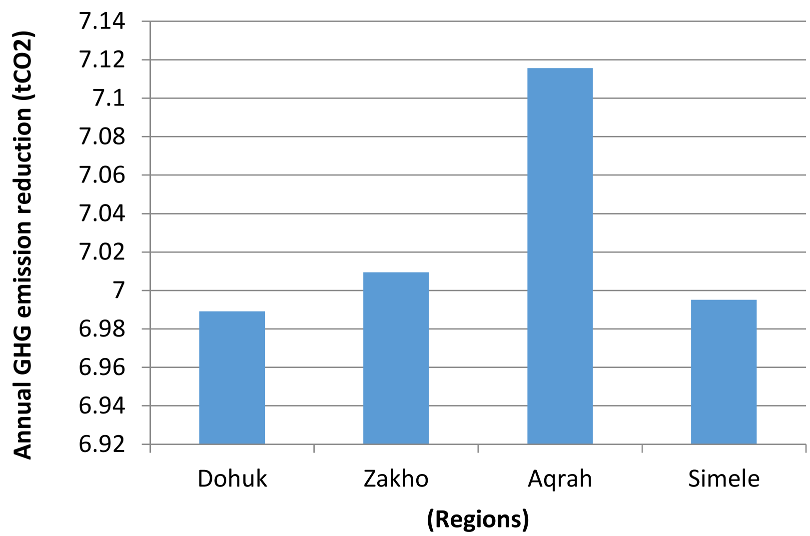

Figure 5.7: Annual GHG emission reduction (tCO2)

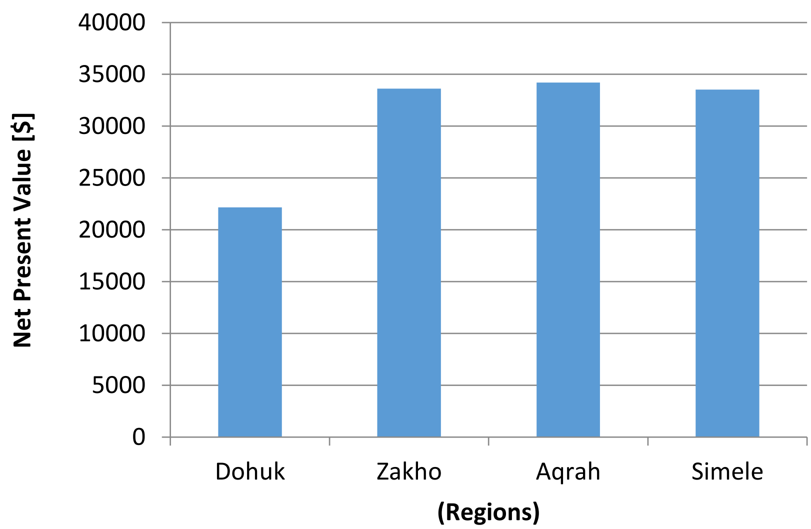

Figure 5.8: Net Present Value ($)

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Table 5.5: Financial parameters performance of 5 kW grid-connected solar projects.

Parameters	Duhok	Aqrah	Simele	Zakho
Annual electricity generation	7737.1227	7759.4769	7877.0869	7743.708
CF (%)	17.3183	17.3683	17.6316	17.333
Annual GHG emission reduction (tCO2)	6.9892	7.0094	7.1156	6.9951
Pre-tax Internal Rate of Return - equity (%)	31.58	31.67	32.14	31.61
Pre-tax Internal Rate of Return - assets (%)	17.85	17.9	18.15	17.86
Simple payback (Year)	6.7997	6.7801	6.6789	6.7939
Equity payback (Year)	3.5736	3.5626	3.5057	3.5703
Net Present Value ($)	22179.21857	33624.41858	34213.80283	33545.39428
Annual life cycle savings ($/year)	1203.7975	1344.9767	1368.5521	1341.8158
GHG reduction cost ($/tCO2)	-172.2369	-191.8821	-192.3304	-191.821
Energy production cost ($/kWh)	0.0328	0.0271	0.0267	0.0272

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the current study, the following conclusions can be drawn:

- The potential of solar energy in the selected regions was evaluated using monthly solar radiations using NASA data. Moreover, it was noticed all the selected regions have high solar resources and rated good or excellent. This indicates that PV systems can be installed in all regions, and the most suitable region is Aqrah and is rated as excellent.
- An economic analysis of the 5 kW potential of the grid-Connected rooftop PV project was performed in all the selected regions. The four regions selected were found to be suitable for installing photovoltaic systems, and the average electricity generated was 7,779.34 MWh / year. Installing an Aqrah station with an output of 7,877 MWh / year is more fitting, and the average capacity factor for solar PV plants is 17.41%.
- The Aqrah region project has a maximum reduction in GHG emissions of 7.1156 tCO2. This is then preceded in the Zakho region by the program, with the smallest pollution reduction coming from the Duhok region project.
- It was observed that the region of Aqrah has the lowest electricity cost of 0.0267$/kWh, followed by the region of Zakho with an average value of 0.0271$/kWh. In contrast, the region of Duhok has the highest average electricity cost of 0.0328$/kWh.
- In general, there is no solar energy project in Dohuk Governorate. The current low price for PV units is encouraging, and it is possible to install a PV system in the governorate.
- From a management perspective, the results indicated that the annual life cycle savings (year / $) in the Aqrah region were the highest, reaching 1368.552 (year / $), and the Duhok region had the lowest. It amounted to 1203.798 (year / $).
- Mono-si's PV technology provided a higher net present value (NPV) for Aqrah, with a cost of 34,213.8 ($).

- The cost of reducing greenhouse gases ($/tCO2), reducing the cost of greenhouse gas emissions, and good results were shown in all the selected regions, especially in Aqrah and Zakho regions. The reduced cost of greenhouse gas emissions was -192.33 ($/tCO2) and -191.882 ($/tCO2), respectively.
- In general, developing a grid-connected solar PV system helps to provide energy and a suitable sustainable solution to energy production crises and reduce emissions to improve Dohuk Governorate's environment. Also, it allows for significant cost reductions in economic terms due to the high potential of solar energy in the region, technological progress, and the development of new policies in the PV market sector.

6.2 Recommendations

According to the results found from the environmental, economic, and management aspects. Future studies should identify other areas in the country, such as the central or southern governorates of Iraq, to work on choosing places that have higher monthly solar radiation, as well as improving the economic situation and taking into account the factors affecting it, in addition to developing new policies in terms of solar photovoltaic technology.

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APPENDICES

APPENDIX 1

ETHICAL APPROVAL LETTER

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ETHICAL APPROVAL DOCUMENT

İntihal ve Etik Kurallar Sözleşmesi Formu

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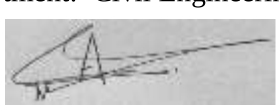
İmza/Signature: 

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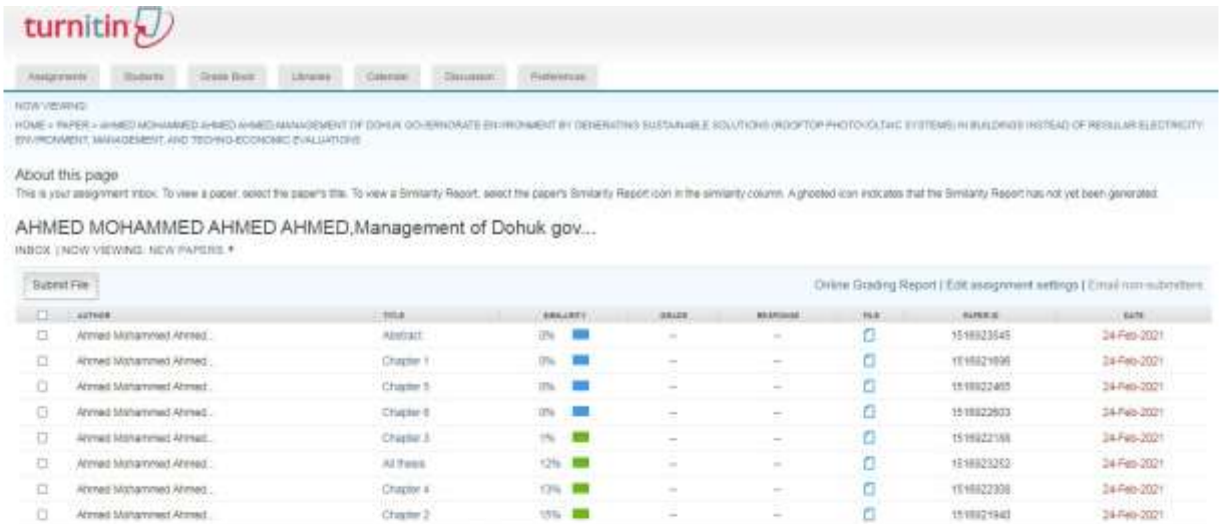
APPENDIX 2

SIMILARITY REPORT



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