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To our families with love and respect.

Preface

This book is aimed at expounding upon the topic of renewable energy, particularly Photovoltaic (PV) solar cells, in Iraq and its neighboring counties. This book is meant to dispel misconceptions and confusion surrounding the use of PV cells, particularly the impact of weather conditions on performance. This book provides important information for Iraqi decision makers, so that they may better understand PV solar cells, their market, and how they provide electricity and preserve the natural environment.

The information contained herein can help bridge the gaps in information regarding PV utilization, assessment, and economics, particularly regarding Iraq and Gulf Collaboration Council (GCC) countries. This book will also provide an excellent reference for advocates of green and renewable energies, along with undergraduate and graduate students.

Baghdad, Iraq — Miqdam Tariq Chaichan
Sohar, Oman — Hussein A. Kazem

Introduction

Since 1991, Iraq has suffered from lack of electricity that affects the everyday life of the Iraqi people. The call for renewable energies made on the street and to Iraqi decision makers falls on deaf ears due to the country's total dependence on fossil fuels, of which Iraq is one of the largest producers worldwide. Most researchers and scholars are unclear about the subject especially the use of photovoltaic cells to produce energy on a quantitative level. Within the Iraqi government, most of the decision makers are opposed to the use of this technology due to an acute shortage of knowledge. This book will unravel the mystery surrounding the use of photovoltaic cells and will stimulate readers to support the manufacture, production, and use of photovoltaic cells in the interests of national security and energy independence.

Contents

Chapter 1
Introduction

1.1 Introduction

The environmental pollution, climate change, and increasing demand for energy across the globe need to have a very serious attention from all political, economic, and technical aspects to avoid the collapse of the environmental and social systems in various countries of the world. Electricity is considered the key element of national and international development in the whole world. There may be sustainable energy resources in each country and appropriate solutions can be provided to all challenges that hinder their utilization through the implementation of advanced technologies that allow optimal use of these energies [1].

Many technological innovations have led the developments in the past few years to face this global dilemma by increasing the efficiency of production systems, reducing costs, and reducing emissions. The entire international energy agency predicts that global energy demand will grow steadily in the near and distant future, despite the volatility of oil and gas prices, the main source of energy in the world with coal. This will generate a strain of countries importing these substances as reflected on its citizens. The International Energy Agency has expected that the energy demand growth will reach up to 1.6% a year or nearly 335 million barrels of oil. The fastest-growing sectors in fossil fuel demand will be electricity generation sector, followed by the transportation sector and the production of petrochemicals. The need for coal and natural gas will grow by about 1.8% each, followed by oil at about 1.4% [2].

The electric energy production is the largest contributor to global warming and acid rain. The increased demand on electricity increases the need for the production and use of fossil fuels which has caused already air pollution; large damages on human health and the environment, such as acidic rain accompanied with global warming; and other forms of pollution. These phenomena caused the contamination of lakes, rivers, and forests, in addition to the destruction of crops and distort monuments and buildings [3].

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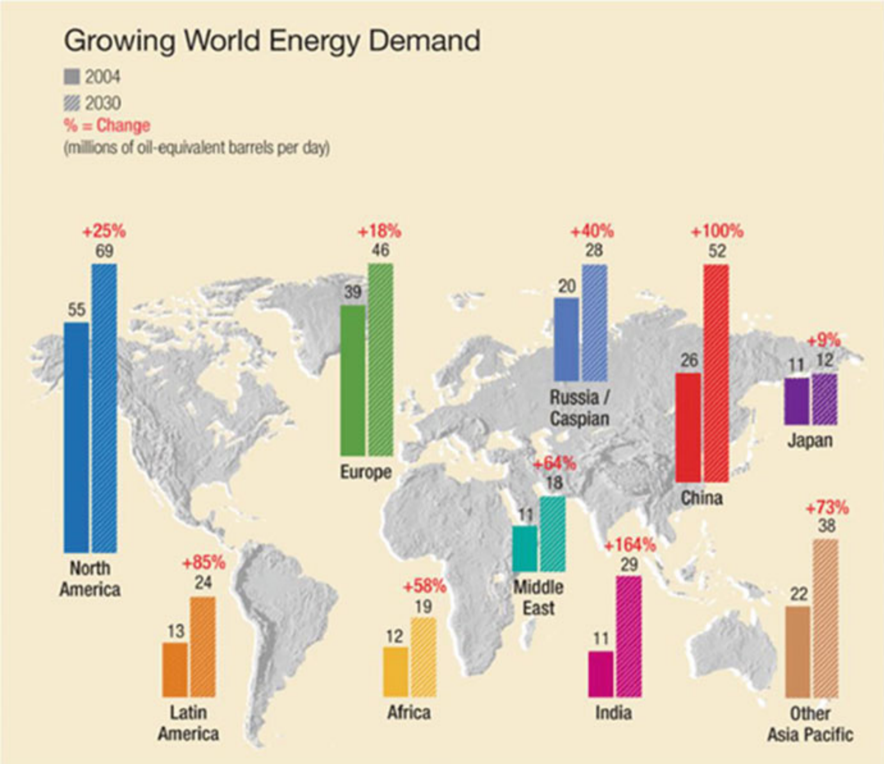

Fig. 1.1 The World Energy Outlook map for the year 2030 [8]

The demand for energy in different continents is uneven growth. The world has seen a sudden increase in energy demand in developing regions, particularly in Asia. It is forecast that global demand in 2030 will increase by 66% compared to 2000 and the share of Asia (excluding Japan) will be accounted for nearly 40% of the growth. Figure 1.1 represents the World Energy Outlook for the year 2030 [4].

Global energy consumption has risen by 2.3% in 2013, compared with 1.8% in 2012. The main part of the increase in global consumption comes from countries outside the OECD with about 51% of global oil consumption. The United States recorded the largest increase in oil consumption in its history in 2013. As for China's oil consumption, it has grown with about 390,000 b/d for the first time since 1999. The fastest increase in oil product demand in terms of size is for light distillate oil products and refined products [5].

It is expected that Brent crude oil prices will return back to \$ 100–\$ 120 per barrel in the next few years, although the price had fallen at the end of 2015 and beginning of 2016 for below \$ 35. The need for oil derivatives in the transport and industrial sectors will continue. The large increase in international transportation needs and industrial activities causes a high rise in the demand for oil and gas, which represent the main sources of energy in the world [6].

In addition to oil, the global consumption of natural gas has grown by 1.4%, and the growth was higher than the average in the OECD countries with about 1.8% and less than the average outside the OECD countries with about 1.1% [7]. Natural gas production has grown globally up to 1.1%. Natural gas trade over the world grew by 1.8% in 2013. The global liquefied natural gas trades have revived, starting from 2013. Qatar is considered today as the biggest exporter of liquefied natural gas (32% of world exports). Demand for natural gas trade between the regions has increased rapidly; while it was 65 billion cubic feet per day in 2010, it will jump to 116 billion cubic feet per day in 2035. At this rate, growth can be an increase of 77% higher than the amount of the gas produced at the present time. One important question is whether gas production can be increased to cover the demand. It is expected that the crude oil production from traditional sources will be lowered with time. In contrast, the liquefied natural gas production will increase rapidly, so the expected emergence of a new source of liquid hydrocarbons that will meet the demands of a long-term [8].

Oil produced from shale formations rich with hydrocarbonate is considered as one of the fastest-growing trends now in the field of exploration and production industry for oil and gas [1]. The shale oil forms from organic materials and stones and clay composed, and because low permeability of these rocks is limited, the hydrocarbons in the rock are not able to move easily through the rock, except over millions of years (geological space of time) [9]. One of the main reasons for the delay of the production of oil shale spread is the high-cost methods and technologies extracted by horizontal drilling and a process known as hydraulic fracturing. During the past years, the application of both techniques (horizontal drilling and hydraulic fracturing) has been used safely to increase the economic value of the oil reservoirs and shale gas. It is expected in the next decade the widespread of these two techniques all over the world to raise oil and gas production to meet the rising global demand for energy [10].

The oil, which is nonrenewable energy source, as a limited natural resource is being depleted in continuous and elevated rate. The maximum rate of production in any region has reached its peak to meet the demand and take advantage of the high prices. Hubert (1956), an American geologist, was first to use the concept of peak oil. He said that "oil production looks like a bell curve." This includes the peak of the curve extraction followed by a quick dip. Hubert had expected, according to his model, that the United States would face a shortage of oil production in the 1970s, and that is what actually happened [11]. We must understand that there is a complex correlation between oil prices and the financial crisis. The growth of oil production stopped due to its arrival to the summit of production coinciding with the fast increase in prices. For the first time since 1970, many of the importing countries forced to reduce their consumption of oil. Controversy still exists to this day whether the oil quantities produced will decline irreversibly or they will return to the normal pattern of growth [12].

Energy affairs can be considered in any country as a very important national issue. The energy availability achievement in any country is essential for the economic and social stability. The energy consumption per capita is used as an

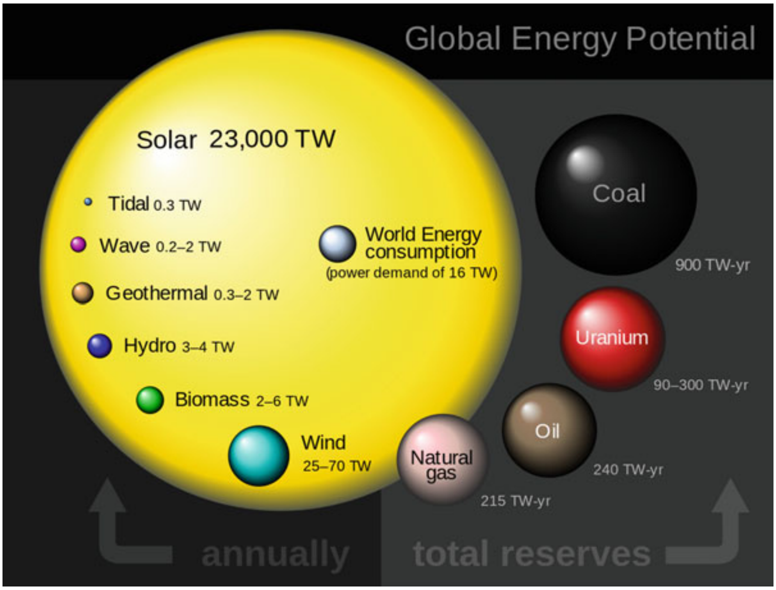

Fig. 1.2 Comparing renewable and nonrenewable energy sources

indicator to measure prosperity in any society. The oil prices impact many imported energy countries, while the other producing countries plugging a part of its energy demands from its present production [13]. The increase of fuel prices has exhausted the imported countries' budgets and influenced a direct impact on their economic growth rate. Many renewable energy sources can replace fossil fuels, especially in the field of electric power generation. As examples of these resources are hydraulic power, nuclear power, and biofuels that come from a large base in the form of fuel wood and agricultural and animal waste [6]. Comparison of global energy potential is shown in Fig. 1.2.

1.2 Solar Energy

Solar energy is a carbon-free energy source that is available all over the world. Some countries are within or close to the solar belt and have long sunny hours, causing high insulation levels, making them in an ideal location to take advantage of solar technologies. Figure 1.3 shows the range of solar irradiation around the world [14]. The weather conditions are important factors affecting the use of solar energy applications. It is possible to take advantage of this energy which is available for free and distributed on a large scale to improve social and economic conditions of the people living in remote areas as well as those who live in cities. The sun power is considered an attractive alternative because it is available and renewable resource with the production of any contamination such as conventional fuel and can be used

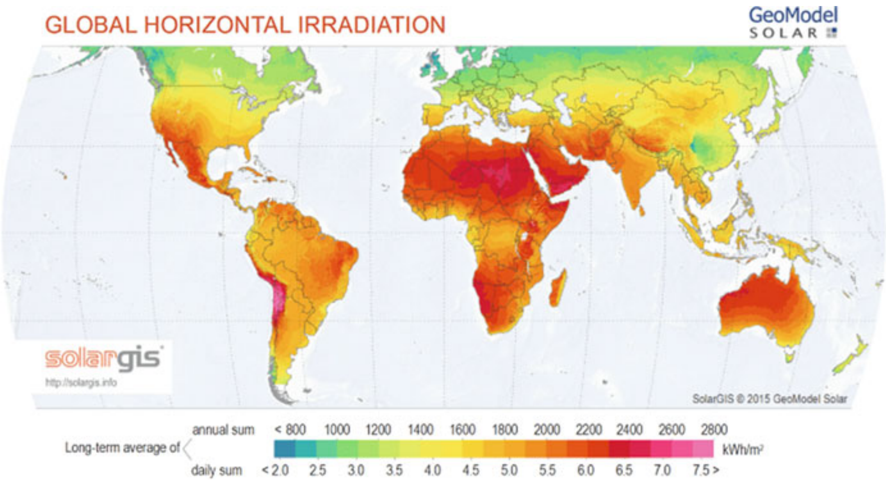

Fig. 1.3 Global solar irradiation map [21]

for heating and cooking [15]. There are aspirations to increase the use of this energy to take a good place and to replace the current fossil fuels in large percentages, especially since the core technology is already available and will continue its modifications.

Solar energy can be used to generate electricity in two methods: concentrated solar power (CSP) and photovoltaic [16]. CSP uses the concentrated sun's rays to generate heat and steam to rotate conventional turbines. Finding solutions linked the generating capacity of the CSP plant with storage; CSP plants can generate electricity that can be saved and used when needed for several hours after generation. A photovoltaic solar energy transforms sunlight directly into electricity systems. The demand for PV systems increased significantly since 2000 after the Germany, and later in Spain, expanded their use [17]. There has been a great addition to the power of polysilicon panels (to a large extent in China) accompanied with PV module prices which fell by 75%. The solar power capacity has grown dramatically in recent years, and its costs have decreased at the same time. PV technology can be used in stand-alone systems for rural telephone stations, transmitting stations, high-speed road emergency telephones, and cathodic protection. Also, this technology can be used for operating water pumps that are used for drinking purposes, as well as irrigation. The private and general sectors in any country have to spread and publish the use of PV system culture [18].

The advantage of solar energy employment in remote areas will be high as most of the residents of these areas need electrical power to meet their needs, which vary from one user to another [19]. Solar power can be considered as the best solution for these areas. The accreditation on technologies such as solar domestic water heating and cooking will reduce the dependence on fossil fuels. The construction of large plants to generate solar electricity will reduce the import of oil and gas significantly [20].

Iraq is a neighbor to the Red Belt that represents the most productive solar areas and has the highest summer temperature. This privileged location and its great advantage in producing electricity locally using solar energy will be presented in detail in the coming chapters.

1.3 Wind Energy

Countries that have a coastline can use the wind energy as well as in the desert areas with the availability of the required wind speed [22]. The investment in this sector for the countries that have the wind data, and the areas that can construct the wind turbines to use of wind energy successfully, must advance strongly. The success of any new technology demands high educational and cultural programs to make people realize the potential of renewable energy, especially wind power. The wind power has a huge generation potential of electricity; it is a technology that can compete traditional energy sources [23]. The wide spread of wind power depends largely on the environmental conditions that may create some problems. Facing the challenges of wind energy technology, such as high installation costs, the fluctuations in its output, and the need to connect it to the electric grid, is a primary step for widespread use of wind energy. Global interest has grown with wind energy generation, and its own technology has been improved. The new technologies of wind turbines can capture wind with high efficiency and become ready to work in embedded areas which also spread the use of wind farms on a large scale. However, these techniques are still having high installation costs which slow down its spread. The wind turbine power stations reduce the carbon concentrations in the atmosphere. It is a low-impact environment technology [24].

1.4 Hydro Energy

When there is an availability of hydroelectric resources, these resources must be used wisely to produce cheap electricity. This renewable energy has the lowest rates of greenhouse gas emissions compared with other sources of energy [25]. The water in the reservoirs is used for the storage of energy that is used to generate electricity when the demand on electricity increase and keep it in the tank when the demand reduces [26]. Hydropower stations are currently available in various capacities with largest production in the natural waterfalls and can be controlled easily and help to reduce the dependence on oil and gas. These stations are built on waterfalls and have the ability to permanently generate electricity, and the available power can be equipped to remote populations who suffer from lack of the main network [27]. This alternative energy, unfortunately, has less growth than other renewable energies. Most predisposing sites for the construction of dams and stations had already been sanctioned, and the expansion of the establishment of new ones is limited [28]. The establishment of dams affects the environment by isolating large ecosystems or creeping it in a way that hurts migration of fish and causes the killing of many kinds of animals. Dams also affect water quality and temperature.

1.5 Biomass Energy

Biomass is produced from raw materials such as biological woody biomass crop or algae. Biomass consists of developing plants or the remnants of growing things, which include trees and grasses, crops and agricultural wastewater plants, and animal dung and biofuels such as ethanol, biodiesel, and other liquid biomass [29]. Sun can be considered the source of wood and all other biomass; as long as the wood is growing constantly, it can be a renewable source of energy, which is available as long as the sun shines. Biomass is converted into liquid fuel through the conversion process into gas for the production of syngas [30].

Biogas is one of the most common types that contain energy, and it makes optimal use of natural resources valuable. It provides a clean gas (free of soot) to meet the needs of cooking as well as bio-fertilizer-enriched fertility/productivity to improve the agricultural land [31]. The biogas technology is one of the best options that can take part of the fossil fuel dependence. The consumption of wood compensation will facilitate the recycling of agricultural and animal waste and bio-fertilizers. Biomass is clean and renewable and will contribute to the protection of the environment and the sustainability of the ecosystem and the preservation of biodiversity [32].

Biofuels can replace fossil fuels in transport sector. Many countries have programs for the production and use of biofuels and been working on the replacement of certain ratios of fossil fuels by blending with biofuels. Statistics indicate that the addition of biofuels, such as ethanol, which is popular in Brazil, with the gasoline, will evolve up from 100 billion liters in 2010 to 190 billion liters in 2020 and to 300 billion liters in 2030 [33]. Biodiesel consumption has grown rising from 50 billion liters in 2010 and is expected to double this figure in 2020 and up to 300 billion liters in 2030. All available data confirms that the use of biomass and waste in power generation will double more than once in 2030.

1.6 Geothermal Energy

Natural heat can be captured from below the earth's surface and used to generate electricity in geothermal application. This type of available energy has fixed rate and reduces the storage concerns as the case with some other renewable energy sources [34]. The areas near the harbor area of active volcanoes can pick up this kind of power easily as these spaces in the Pacific regions and the Western United States. In Iceland geothermal power plants produce about 25% of the country's need of electricity. There is a way for the use of geothermal energy which is digging deeper into the ground to mimic the design of water tanks, steam, and natural hot. This technology can be developed as this energy has the ability of the solution to be influential in terms of its enormous potential. Even today, there are few available studies on the environmental research on the benefits and harms of this energy, but many utility companies in Europe and the United States and Australia have invested in this technology [35]. The development of drilling technologies with low costs that can reach very deep into the ground with the cheaper price will increase investment in this area. The cost of electricity generated from geothermal energy is considered the biggest obstacle to the development of this technology at the present time. The high cost of geothermal energy is competitive with other sources of electricity currently.

1.7 Ocean Tidal and Wave Energy

The power generation from tides and ocean waves can be regarded as a promising source of energy for the future. So far, there are many challenges associated with how to store and transport this energy efficiently, which prevented this technique from becoming a source of renewable energy [36]. In addition, the areas available to produce the potential capable of generating this type of energy are present in some locations around the world, especially in France, Canada, and Russia. However, even at those sites, the construction costs are high; also, it should increase the electricity production of tidal power stations efficiently. The first commercial power station in the world is that which was constructed in the United Kingdom to provide up to 26 gigawatts of electricity linked to the energy grid. This electricity is considered enough to supply 5000 households in this country [37].

Among the primary renewable energy resources (solar, wind, hydropower, geothermal, biomass, and ocean), solar energy offers exceptional potential for three main reasons: First, the solar energy is always available and is not harmful to the environment. Solar energy is noiseless, without movement, smoke, dust, and waste. There is no any kind of physical risks with the use of this energy. Second, the possibility of solar power generation is virtually unlimited and never runs out. Finally, it is expected that the cost of solar power will compete with those produced from traditional fossil fuel sources, which will be depleted within the next years [38].

References

1. International Energy Agency (2010) World energy outlook. International Energy Agency, Paris. ISBN: 978-92-64-08624-1
2. Krauss C (2014) Conflict in oil industry, awash in crude. The New York Times

3. http://www.nytimes.com/2014/02/13/business/energy-environment/an-oil-industry-awash-incrude-argues-over-exporting.html?_r=0
4. Beides H (2013) Pan-Arab interconnection and development of Arab power markets: based on recommendations made by the joint League of Arab States/World Bank Study on arab electricity integration institutional and regulatory framework, GCCIA Power Trade 2nd Forum, May 2013
5. Future Energy Challenges in the GCC Region (2014) A brief on Saudi Arabia's Energy Efficiency Program 4, Prince Abdulaziz Bin Salman Al-Saud, The Oxford Institute for energy studies issue 6, May 2014
6. Greene DL, Hopson JL, Li J (2006) Have we run out of oil yet? Oil peaking analysis from an optimist's perspective. Energy Policy 34:515–531
7. Campbell CJ (2005) The oil crisis. Multi-science Publishing Co. & Petro-consultants, SA, Cambridge Energy Research Associates (CERA) (retrieved on the Internet 15.10.07 /http://www.cera.com
8. International Energy Agency, World Energy Outlook (2011). Available at: https://www.iea.org/publications/freepublications/publication/WEO2011_WEB.pdf
9. Levine S, Carpenter P, Thapa A (2013) Outlook for North American trade in LNG and Oil, Presentation to LSI energy exports in the Northwest Conference, Seattle, WA
10. Jadwa Investment (2013) Outlook for unconventional oil & gas production, focus on tight oil and shale gas production impact on Saudi Arabia, December 2013. Available at: http://www.jadwa.com/en/media/get/20131217_The-Outlook-for-Unconentional-Oil-Gas-Production-Fullreport.pdf
11. Stanic J (2014) Unconventional Oil and Gas Production Drives Trends in Water management and Treatment, Global Water Intelligence, Oil and Gas Facilities, August. Available at: https://spe.org/en/print-article/?art=269
12. BP (2014) BP statistical review of world energy
13. Hubbert MK (1974) US energy resources: a review as of 1972, Background paper prepared for the US Senate Committee on Interior and Insular Affairs, 93rd Congress, 2nd Session, Serial 93–40 (92–75). US Government Printing Office, Washington
14. Neij L (2008) Cost development of future technologies for power generation – a study based on experience curves and complementary bottom-up assessments. Energy Policy 36(6):2200–2211
15. Viebahn P, Lechon Y, Trieb F (2010) The potential role of concentrated solar power (CSP) in Africa and Europe: a dynamic assessment of technology development, cost development and life cycle inventories until 2050. Energy Policy. https://doi.org/10.1016/j.enpol.2010.09.026
16. Breyer C, Gerlach A, Mueller J, Behacker H, Milner A (2009) Grid-parity analysis for EU and US regions and market segments – dynamics of grid-parity and dependence on solar irradiance, local electricity prices and PV progress ratio. In: Proceedings of the 24th european photovoltaic solar energy conference, Hamburg, pp 4492–4500
17. Sharma A (2011) A comprehensive study of solar power in India and world. Renew Sust Energ Rev 15(4):1767–1776
18. Blanco MI (2009) The economics of wind energy. Renew Sust Energ Rev 13:1372–1382
19. Boccard N (2009) Capacity factor of wind power realized values vs. estimates. Energy Policy 37:2679–2688
20. EWEA (2009) Wind energy, the facts. European Wind Energy Association, Brussels
21. GeoModel Solar (2015) "SolarGIS-Solar-map-World-map-en.png" in free download of solar radiation maps: global horizontal irradiation (GHI). [Online]. Available: http://solargis.info/doc/free-solar-radiation-maps-GHI [December 13, 2015]
22. Nielson P, Lemming JK, Morthorst PE, Lawetz H, James-Smith EA, Clausen NE, Strøm S, Larsen J, Bang NC, Lindboe HH (2010) The economics of wind turbines. EMD International, Aalborg
23. Avarado-Anchieta CA (2009) Estimating E&M powerhouse costs. Int Water Power Dam Constr 61(2):21–25
24. BMU (2008) Further development of the Strategy to increase the use of renewable energies within the context of the current climate protection goals of Germany and Europe. German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Bonn

25. Hall DG, Carroll GR, Cherry SJ, Lee RD, Sommers GL (2003) Low head/low power hydropower resource assessment of the North Atlantic and Middle Atlantic Hydrologic Regions. DOE/ID-11077. U.S. Department of Energy Idaho Operations Office, Idaho Falls
26. Hall DG, Cherry SJ, Reeves K, Carroll GR, Lee RD, Carnoll GR, Sommers GL, Verdin KL (2004) Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources Idaho National Engineering And Environmental Laboratory. Available at: https://www1.eere.energy.gov/water/pdfs/doewater-11111.pdf
27. Krewitt W, Nienhaus K, Klebmann C, Capone C, Stricker E, Grauss W, Hoogwijk M, Supersberger N, Winterfeld UV, Samadi S (2009) Role and Potential of Renewable Energy and Energy Efficiency for Global Energy Supply. Available at: https://www.ecofys.com/files/files/report_role_potential_renewable_energy_efficiency_global_energy_supply.pdf
28. Teske S, Pregger T, Simon S, Naegler T, Graus W, Lins C (2010) Energy [Revolution 2010—a sustainable world energy outlook]. Energ Effic. https://doi.org/10.1007/s12053-010-9098-y
29. Alfstad T (2008) World biofuels study: scenario analysis of global biofuels markets, BNL-80238-2008. Brookhaven National Laboratory, New York, p 67
30. Kline KL, Oladosu G, Wolfe A, Perlack RD, McMahon M (2007) Biofuel feedstock assessment for selected countries, ORNL/TM-2007/224, Oak Ridge National Laboratory, Oak Ridge, p 243
31. Haas MJ, McAloon MJ, Yee WC, Foglia TA (2006) A process model to estimate biodiesel production costs. Bioresour Technol 97(4):671–678
32. Jechura J (2005) Dry mill cost-by-area: ASPEN case summary, National Renewable Energy Laboratory, Golden, p 2
33. Balcer M (2000) Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Cracow, Poland, p 107–114 (ISBN 83-87854-62-X)
34. Lund JW, Boyd TL (2009) Geothermal utilization on the Oregon Institute of Technology campus, Klamath Falls, Oregon. In: Proceedings of the 34th workshop on Geothermal Reservoir Engineering, Stanford University, CA, USA, (ISBN: 9781615673186)
35. Kerr D (2007) Marine energy. Philos Trans R Soc Lond Ser A (Math Phys Eng Sci) 365 (1853):971–992
36. Charlier RH (2003) Sustainable co-generation from the tides: a review. Renew Sust Energ Rev 7(3):187–213
37. ETSAP (2010b) Marine Energy Technology Brief E13 – November, 2010, Energy Technology Systems Analysis Programme, International Energy Agency, Paris. Available at: www.etsap.org/E-techDS/PDF/E08-Ocean%20Energy_GSgct_Ana_LCPL_rev30Nov2010.pdf
38. Gastli A, Armendariz JSM (2013) Challenges facing grid integration of renewable energy in the GCC region, EU-GCC renewable energy policy experts' workshop, an international meeting organized by the Gulf Research Center, EPU-NTUA and Masdar Institute on November 24–27, 2013 in Abu Dhabi

Chapter 2
Iraq

2.1 Introduction

Iraq, called officially the Republic of Iraq, is a parliamentary, federal republic according to the Constitution of Iraq. This country consists of eighteen provinces; the capital of Iraq is Baghdad. Iraq is overlooking the Arabian Gulf; it is one of the West Asian countries; and this state is a member in the Arab League and in the Organization of Islamic Countries. Iraq is an oil-rich country and one of the founders of the OPEC. Iraq is considered as the cradle of the first civilizations in the world, Sumer civilization, which included all the space between the Tigris and Euphrates rivers and extended its borders to Syria and Persia (Iran today). Its authority extended to the southeast region of Anatolia (now Turkey) also. The Iraqi civilizations of Mesopotamia connect ancient civilizations in Egypt and India. Iraq has been home to many civilizations, the most important of the Sumerian, Babylonian, Chaldean, Assyrian, Medes, Seleucids, the Parthian Empire, Empire and Romania, and the Sassanids, and Manathira, the Caliphate, and the state of the Umayyad, Abbasid state, and the Mongols, the Safavid state, and Afsharid Dynasty, and the Ottoman Empire, then the British Mandate, and then the Kingdom of Iraq, at the end the republic [1].

Arabian Gulf is the only seaport of Iraq to the world, and the length of the seacoast of Iraq is about 58 km away. Iraq has several ports on the Persian Gulf, such as Umm Qasr and the Faw port in the province of Basra, southern Iraq. The estimated number of people in Iraq in July 2015 is up to 37,056,169 people. Iraq has a large diversity of terrain. In northern Iraq, there are mountains, valleys, and Hamrin Mountains; in the center and south, there is the fertile alluvial plain between the Tigris and Euphrates rivers. In the west of Iraq, there is arid desert and Levant desert. Iraq's Tigris and Euphrates rivers, which the burst their banks originated all the civilizations of Mesopotamia. There are natural marshes in southern Iraq, which contain animals and environment that do not exist elsewhere in the world. These marshes are Haur Al-Hammar and Haur Al-Hawizeh. This country contains a

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number of artificial lakes as Lake Tharthar and Lake Razazah and some other natural lakes as Sawa Lake [2].

Iraq is the country of many of the prophets, most notably the Prophet Ibrahim, Yunus, Ezekiel, Daniel and Uzair, Nahum, and Adam, Noah, Hud, and Saleh. This land contains the body of Solomon and Ayoub. The pro-Islamic, Christian, and Jewish novels confirm the existence of these prophets' shrines. Shrines for many of the leaders of the Muslims can be found in Iraq such as Imam Ali, Imam Hussein and his brother Abbas, Al-Kazemyn imams, Al-Askarian imams, Imam Al-Mahdi, Imam Abdul-Qadir Gilani, and Imam Abu Hanifa and many shrines of the children of imams and Sahaba such as Salman the Persian and followers [3].

Iraqi modern border was painted mostly in 1920, when the Ottoman Empire was divided by the Treaty of Sevres. Iraq was placed under the British mandate authority. In 1921, it established a constitutional monarchy and became independent Kingdom of Iraq from the British Mandate in 1932. In 1958, the monarchy was dropped, and the Republic of Iraq was established. In 1968, the Arab Socialist Baath Party ruled Iraq and continued governing it until 2003. After the invasion of the United States and its allies in Iraq in 2003, Baath Party authority was collapsed, and parliamentary elections were held in the multiplicity of 2005. The American presence in Iraq ended in 2011 [4].

In 1980, Iraq went to war with Iran that lasted for 8 years from September 21,1980, until August 8,1988. In August 2, 1990, Saddam Hussein invaded the State of Kuwait which caused the outbreak of the second Gulf War in 1991. The United Nations has imposed strict economic blockade starting from August 6, 1990. The Security Council continued to impose economic sanctions against Iraq and accused Iraq of violating the obligations of the nineties. This unfair embargo on Iraq caused humanitarian, environmental, and economic damages, as it caused the destruction of the country's economy and the decline in health and education level and caused a humanitarian disaster because of a lack of food and medicine.

Iraq is considered as one of the main oil and natural gas suppliers and reservoirs of the world. Due to its high wealth, its population increases steadily. The expected rising of the population of Iraq is to reach approximately 64 million in 2050, while it is about 32 million in 2010. The major concentration of the population of approximately 75% lies in urban centers. Iraq suffers from discontinuous electricity supply and increase difference between supply and demand. Iraq since two decades till now suffers from a growing shortage of electrical energy due to the increasing rise in demand (see Fig. 2.1). Iraq entered two severe wars (1991 and 2003) that destroyed its underlying constructions. The reconstruction rates don't work in the required levels due to internal and external issues. Despite considerable increments in generating electricity capacity in recent years, electrical power plants fail to supply the required demand for power due to limited production capabilities and numerous defects due to deterioration [5].

Iraq's economy depends heavily on oil. However, the oil is not the only supplier of Iraq, like the rest of the Arab Gulf states. Iraq is a founding member of OPEC, and it started exploration and export oil since 1925. The total proceeds of Iraqi oil exports in 2000 were more than $ 20 billion. The Iraqi oil production before the US invasion

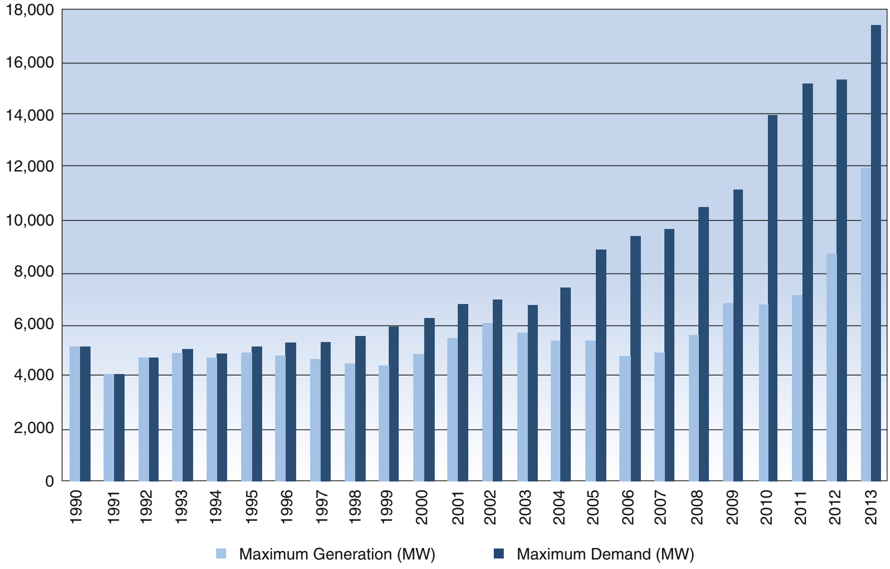

Fig. 2.1 Generation vs demand 1990–2013

to Iraq was at least two million barrels per day. The refining capacity of more than 500 thousand barrels per day by the largest number of oil refineries, compared to all the Arab countries, is 12 refineries in 2000 [6].

The Iraqi hard oil reserves are about 112 billion barrels, making it the second largest oil reservoir known in the world after Saudi Arabia. The estimated and fixed reserves of Iraq are at about 150 billion barrels, making it the second of the world after Saudi Arabia. Some experts expected the reserves in Iraq to exceed its counterpart in the Gulf States after the completion of research and exploration in the rest of Iraqi territory that has not received a geological survey in full for the day [7].

Iraq's numerous wars over the past decades have caused it to be unable to use modern technologies to drill oil wells, which improve the extraction of oil from discovered reservoirs. Today, if Iraq uses these new technologies, it can extract the future ability to more than 360 billion barrels. With the current rate of oil extraction depending on the currently available abilites, Iraq can continue to extract oil for three and a half centuries, because this country has enormous oil capacity, according to analysts. From the 70 oil fields discovered in the oil sector, only 15 are exploited. These fields currently need large sums of investment and reforms to increase its exploitation and production [8].

The bulk of Iraq's oil reserves is concentrated in Basra Province in the south, where there are 15 fields consisting of 10 producing fields and 5 still waiting for development and production. These fields contain oil reserves estimated at more than 65 billion barrels or almost 59% the proportion of the total Iraqi oil reserves. The oil reserves in the provinces of Basra, Maysan, and Dhi Qar together counted for about 80 billion barrels, which equal to 71% of Iraq's total reserves. The estimated oil reserves in Kirkuk, located in the middle of Iraq, about 13 billion barrels, constitute for about 12% of the total Iraqi oil reserves [9].

The agricultural sector is an important part of the Iraqi economy because of the richness of the land of Iraq to the water. The most important products are the seeds, grains, dates, vegetables, and fruit. The agricultural areas concentrate around the Tigris and Euphrates rivers and its branches in the country. However, the drought that hit the central and southern Iraq because of the climate changes in the past two decades has caused a dramatically decline in agriculture in Iraq [10].

The military actions and before it the unsuccessful policies of the Government of the Baath Party (1968–2003) caused significant damages to the agriculture sector of Iraq. Also, the unjust blockade imposed by the United Nations on Iraq and the use of oil for food and medicine for the import of vegetables and fruits and agricultural products caused in the delay of irrigation projects and reducing the area under cultivation. This blockade was accompanied with long years of drought due to unfavorable weather conditions. Experts predicted that Iraq would be importing countries of agricultural products in the foreseeable future.

Despite the presence of many rivers, the fishing industry has been relatively limited in Iraq. It depends heavily on marine species in the Arabian Gulf. The amount of fish coughed in 2001 estimated to be up to 22,800 tons of fishing [11].

In Iraq, the mining industry has been confined to extract the relatively small amounts of phosphate in western Iraq Akashat area and salt and sulfur near Mosul in the middle. In the 1970s, the mining industry in Iraq strted to bear fruit. This industry development was hindered by the Iran-Iraq war (1980–1988) and penalties of the unfair siege and occupation in 2003.

Industries are diverse in Iraq and the Iraqi industry is characterized by quality despite the age of the factories, machinery, and circumstances experienced by Iraq. Among these industries are construction materials, petrochemical, tobacco, and leather industry. There are plans currently understudy to support the domestic industry and encourage the investments in this sector [12].

Iraq suffers from high environment pollution that is multiplied due to negligent handling for decades. One clear manifestation of environmental pollution increase is the salinity of millions of acres of land in the central and southern regions of Iraq, which is always one of the most fertile areas, and its transformation into a barren land unsuitable for agriculture. This pollution has intensified and grown because of Baath Party government's failed policies between 1968 and 2003. This government put many wrong plans and policies. The marshes were drained and converted to nonarable land, the trees were cut, and the forests were destructed in all parts of Iraq. This government led Iraq to three cosmic wars that caused more pollution. In the second Gulf War, the United States shot down thousands of tons of bombs, some of which contain depleted uranium. The unfair blockade which lasted for more than 12 years caused a considerable pressure on the Iraqi environment and worsening pollution that reached limits which began to directly threaten human, animals, and plant life [13].

Radioactive contamination is a high-impact pollution for soil, water, and air, so its hazards are very large. During the first Gulf War in 1991, the contamination caused by missiles loaded with tons of explosives, many of which were loaded with depleted uranium used by the Allied forces, led to an increase in pollution, which requires much attention because it involves radiological and chemical notification with an impact spanning millions of years. Military operations of the allies in the third Gulf War have caused third complete collapse of the infrastructure facilities of water purification and wastewater treatment plants and disposal system and become pumped directly into the Tigris River, including contaminated groundwater [14].

The industrial and household waste causes pollution that impacts significantly the water and public health due to excessive waste. These pollutants are resulting from various factories such as iron, aluminum, wood and plastic materials, or household waste. The long-live of these pollutants cause hazards on public health, because it contains organic materials can be subjected to rot and damage escalate foul odors damage and be a help to the rapid multiplication of bacteria and fungi and insects harmful environment. Small- and medium-sized cities produced daily thousands of tons of waste. It is a very important issue to get rid of household waste which is the duty of the official who preserves the level of health in all countries. The industrial development must be programmed and take safety procedures into account to safe the Iraq environment. The urban development and the growing population of random and consumer demands have led to the increase of solid waste, including exacerbating this problem and increasing their damage [15].

Nowadays, due to the increasing pollution that resulted from oil drawing out and burning, the appeal for using renewable energy sources such as solar energy has increased in Iraq. Solar energy is an important alternative to compensate the increase of the energetic consumption of the planet. Iraq has long hours of sunshine that exceeds 3000 h of solar radiance per year. The hourly solar intensity varied between 416 W/m^2 in January and 833 W/m^2 in June. Photovoltaics when exposed to light are capable of producing electricity without any harmful effect to the environment. PV can generate power for many years while requiring only minimal maintenance and operational costs [16].

2.2 Iraq Geography

The understanding of the importance of Iraq and its complex role in determining the current events in the region and the world needs to study the importance of its location as indicated by many experts in the administration of the US Army Military Academy. Iraq is located between latitudes 29° 5′ and 37° 22′ N and the longitudes 38° 45′ and 48° 45′ E, thus forming the eastern edge of the Arab states (Fig. 2.2). Iraq borders the Islamic Republic of Iran to the east, Turkey to the north, the Persian Gulf to the southeast, Saudi Arabia and Kuwait to the south, and the Hashemite Kingdom of Jordan and the Syrian Arab Republic to the west. The total area of Iraq is 320,438 square kilometers. Iraq is made up of topography such as the basin and the Great

Fig. 2.2 Iraq's shaded relief map

Plains in Mesopotamia in the Tigris and Euphrates rivers surrounded by mountains in the north and east and desert areas in the south and west. The desert represents more than 40% of its land area, while the mountain sails sometimes rise to about 3550 meters above sea level. About 26% of the total area of Iraq is cultivable, as shown by many statistics [17].

According to statistics from the Ministry of Planning of Iraq, the population in July 2011 was 302,399,572 people at a growth rate of 2.399%. The most densely populated city of Iraq is the capital Baghdad, which has a population of 5.751 million. Figure 2.3 shows the distribution/ population density (based on figures and estimates for 2002). About 97% of Iraqi land is barren with little rainfall and irregularity. The high rates of evaporated transpiration that exceed rainfall cause endurance in most parts of the country. During the seasons, the temperature changes significantly (from 10 °C to 40 °C), and this variation appears in the desert areas

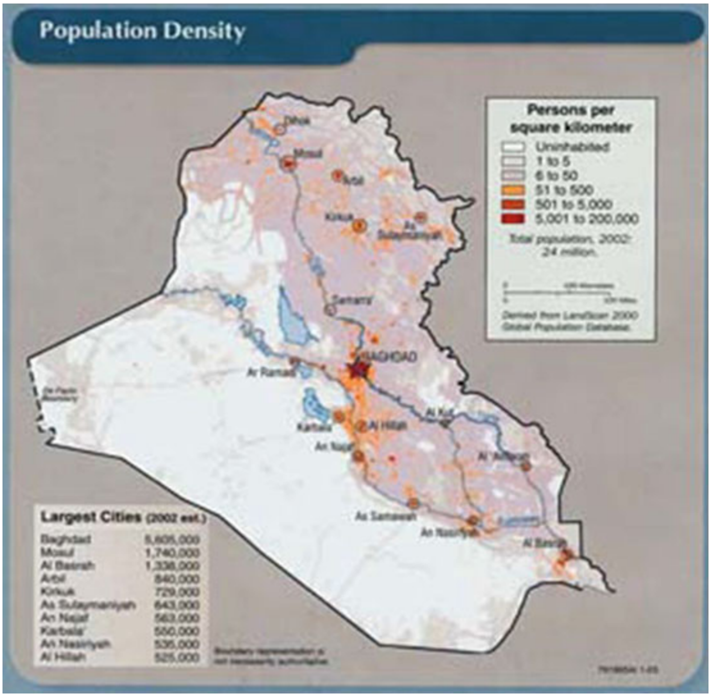

Fig. 2.3 Iraqi population density map

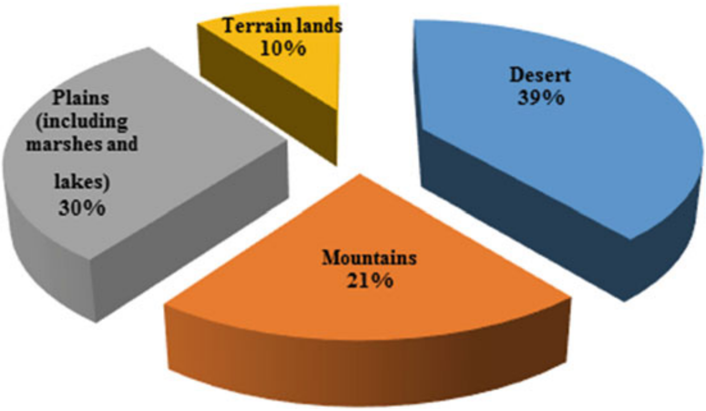

Fig. 2.4 Physical land division of Iraq (%)

during the day. Iraq historically has been an agricultural country and is dependent on irrigation from rivers and waterways in much of its territory. Also, in the northern parts where there are mountains, foothills, and Jazeera desert, it still depends highly on rain-fed agriculture for grain and sheep production. Figure 2.4 shows the physical

Table 2.1 Types of terrain, landforms, and rainfall (mm) in Iraq [31]

Types of terrain/landform	Area km^2	%	Rainfall
Plains	132,500	30	50–200
Undulating/terrain land	42,000	10	250–450
Mountains	92,000	21	400–1000
Deserts	168,552	39	50–200
Total	435,052	100	

land division of Iraq. The arable land accounts for about 26.4% of the total area of Iraq and is about 120,000 square kilometers. There are lands in the northern region of Iraq with a total area of about 40,000 km and the rest of the irrigation areas in the Mesopotamian plains. Table 2.1 represents the types of terrain, landforms, and rainfall [18].

2.3 Iraq Metallurgical Conditions

The description of the climate of Iraq must be done with great care because of its topographic diversity. The northern and northeastern regions of Iraq, which are mostly mountainous in composition, are dominated by the Mediterranean climate. In the other parts, which represent most of Iraq, the prevailing climate is semi-equatorial semiarid continental. Summer in Iraq is very hot and dry, with no clouds or rarely exist. The summer season lasts for more than 4 months, while winter is typically characterized by its mild to cool temperatures with precipitation commonplace. Tables 2.2 and 2.3 illustrate the yearly and monthly rates of regular solar radiation and air temperatures for several Iraqi stations for the period from 1982 to 2013 [19].

Iraq is considered from the countries of high levels of solar exposure radiation. The daily averaged fallen solar radiation ranged from 850 W/m^2 at summer to 450 W/m^2 at winter. Almost all of Iraq has potential areas for establishing large-scale solar utilities. Figure 2.5 shows the daily average for solar exposure in Iraq. Solar energy exposure period in Iraq is available for a long period; Table 2.2 indicates the monthly and yearly rates of the actual day solar radiance (h/day) [20].

In the southwestern half of the country, the mean annual rainfall is less than 100 mm, and it increased to about 140 mm in the center near Baghdad and to about 200 mm east of Sinjar in the north, west of Mandali, and east of Baghdad. The 400 mm rainfall rate passes through Mosul, Erbil, Khanaqin, and Mandali. At the northeast the rainfall increases gradually to about 1000 mm in the Zagros Mountains. However, there is great variation in rainfallfrom year to year especially in the region getting less than 400 mm of rain per year [21]. The majority of Iraq experiences either dry or semidry climate characterized by less than 150 mm of rain per year and high evaporation rates except for the mountainous regions of the north and northeast. Rainfall is very seasonal and occurs in the winter from December to February, except in the north and northeast of the country, where the rainy season is from November

Table 2.2 The monthly and yearly rates for the actual day solar radiance (h/day) for Iraqi stations for the period 1982–2013 [37]

Station	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec	The average
Sulaymaniyah	4.8	5.2	6.7	6.4	9.4	11.3	11.3	11.5	10.4	7.9	6.8	4.8	8.0
Arbil	4.9	5.5	6.8	8.5	8.4	11.2	11.3	10.9	9.8	8.1	6.3	4.9	8.0
Kirkuk	5.2	6.2	7.1	7.7	9.3	11.3	11.2	11.2	10.2	8.4	6.7	5.2	8.3
Mosul	4.6	5.6	6.7	7.9	9.8	11.0	11.9	11.3	10.3	8.1	6.3	4.6	8.2
Najaf	6.4	7.3	7.9	8.4	9.4	11.4	11.5	10.9	9.8	8.4	7.3	6.4	8.72
Khales	5.3	6.2	7.1	7.9	9.3	10.9	10.1	10.6	9.5	7.3	6.7	5.3	7.99
Baghdad	6.1	7.2	7.9	8.6	10.0	11.4	11.3	11.1	10.1	8.2	7.1	6.1	8.7
Al-Hella	6.2	7.2	7.5	8.5	9.6	11.7	11.6	11.3	10.0	8.2	7.2	6.2	8.7
Al-Diwaniyah	6.4	7.3	7.9	8.3	9.4	11.6	11.7	11.3	10.3	8.5	7.1	6.4	8.9
Al-Hay	6.5	7.5	7.9	8.5	9.6	11.7	11.6	11.4	10.2	8.4	6.9	6.5	8.87
Al-Samawa	6.9	7.7	8.1	8.7	9.2	11.3	11.9	11.6	10.2	8.9	7.6	6.9	9.0
Al-Amara	6.2	7.3	7.4	8.7	9.8	11.8	11.5	11.6	10.3	8.1	6.9	6.2	8.8
Al-Nasiriyah	6.5	7.4	7.6	8.2	9.1	9.9	10.1	10.0	9.6	8.1	7.2	6.5	8.32
Al-Basra	6.6	7.6	7.9	8.5	9.6	11.3	11.1	10.9	10.3	8.9	7.6	6.6	8.9
Al-Rutba	6.5	7.4	8.1	8.7	10.0	11.3	11.8	11.6	10.5	8.7	7.6	6.5	9.1

Table 2.3 The monthly and yearly rates for the maximum air temperatures (°C) for Iraqi stations for the period 1982–2013

Station	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec	The average
Sulaymaniyah	9.8	11.6	15.9	23.4	27.5	39.1	39.4	39.1	35.2	28.2	19.7	12.3	24.8
Arbil	11.9	14.8	19.1	24.2	34.7	41.1	41.7	41.1	37.2	30.5	21.6	15.6	27.6
Kirkuk	14.1	15.8	20.3	26.7	34.0	42.9	43.4	42.9	38.2	31.2	22.7	16.2	28.8
Mosul	12.6	14.8	19.3	25.5	32.9	42.8	43.0	42.8	38.2	30.7	21.2	14.5	27.9
Najaf	16.5	18.0	25.5	31.1	37.8	44.2	44.6	44.2	40.7	33.8	24.4	19.2	31.5
Khales	15.4	18.3	23.3	29.2	35.5	42.9	43.0	42.9	38.9	33.0	23.5	17.4	30.1
Baghdad	15.8	18.7	23.8	30.2	36.8	43.8	44.3	43.8	40.2	33.6	23.7	17.6	30.8
Al-Hella	15.3	18.3	22.9	28.7	34.5	40.5	40.2	40.5	37.3	30.2	22.8	17.0	28.8
Al-Diwaniyah	16.9	19.8	25.1	31.4	37.8	44.0	44.3	44.0	40.7	34.7	24.9	18.8	31.7
Al-Hay	17.0	19.9	24.9	31.7	38.5	45.1	45.0	45.1	42.0	35.4	26.0	19.2	32.3
Al-Samawa	16.9	20.3	25.3	32.0	36.9	44.4	44.5	44.4	41.3	43.8	25.8	19.2	32
Al-Amara	16.8	19.9	24.8	31.7	38.7	45.3	45.9	45.3	42.2	35.3	25.7	18.9	32.4
Al-Nasiriyah	17.5	20.2	25.8	32.0	39.0	45.5	45.4	45.5	42.2	35.7	26.1	19.6	32.7
Al-Basra	17.9	20.9	25.9	32.8	39.6	46.1	46.1	46.1	42.6	36.4	26.8	20.1	33.3
Al-Rutba	13.2	15.1	19.8	25.5	31.9	39.1	38.9	39.1	35.9	30.6	21.1	13.9	26.78

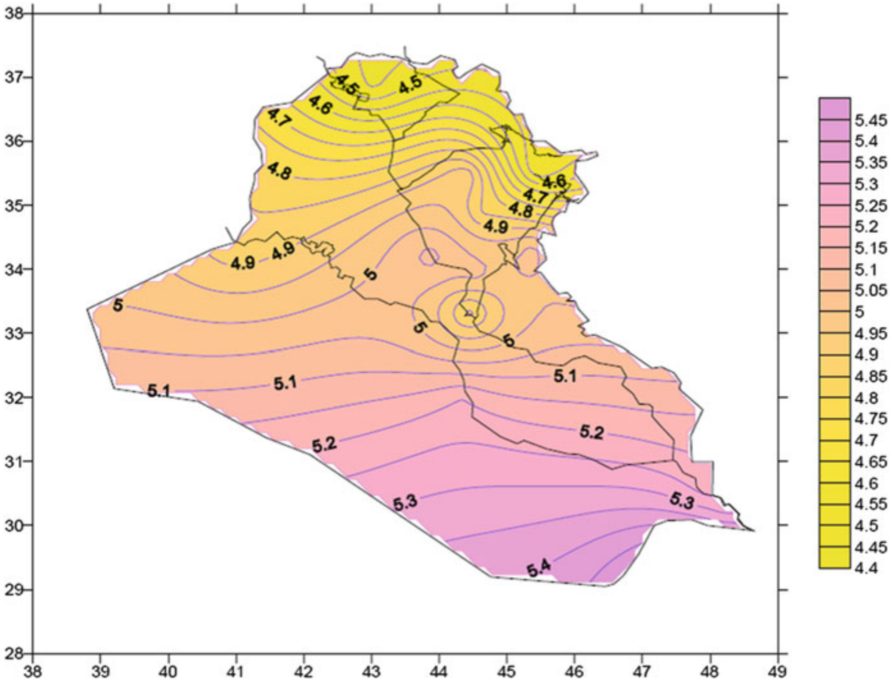

Fig. 2.5 The daily average solar insulation for different locations in Iraq

to April. The surface water levels in Iraq's reservoirs, lakes, and rivers are diminished to critical levels. The inferior management of aquifers and their recharge has impacted the level and quality of groundwater supplies [22]. The outside borders precipitation falling count for more than half of Iraq water. This issue makes Iraq exposed to hazards and climate change due to storage projects in Turkey, Syria, and Iran. Discharge rates in the Tigris and Euphrates rivers, Iraq's primary sources of surface water, have already fallen to less than a third of normal capacity and are expected to drop further in the coming years. Table 2.3 manifests for the maximum temperature rates for several Iraqi stations for the period from 1982 to 2013, while Table 2.4 declares the minimum temperature rates for the same stations at the same period [23].

The weather in summer is high, and the average for July varies from 38 °C to 43 °C in Baghdad. The temperatures throughout the country are similar except in some mountain areas. The average temperature for the hottest summer months is between 43 °C and 50 °C for June, July, and August. The average monthly temperature of the minimum temperature in January is 1 °C in the Western Sahara and the northeastern mountain regions and up to 8 °C in the central part of the country, which represents the plain of the river. The lowest temperatures recorded in Iraq in the last 30 years ranged between −14.5 °C in the northern desert and −8 °C in

Table 2.4 The monthly and yearly rates for the minimum air temperatures (°C) for Iraqi stations for the period 1982–2013

Station	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec	The average
Sulaymaniyah	4.8	5.7	9.6	14.1	19.9	26.6	28.1	27.9	22.2	18.8	11.0	7.3	16.3
Arbil	4.2	4.4	7.9	12.2	17.9	22.8	26.1	32.6	22.3	16.9	9.4	4.8	15.1
Kirkuk	4.8	5.9	9.5	14.6	20.6	25.6	28.7	28.2	24.6	18.9	11.6	6.7	16.6
Mosul	2.3	3.5	6.8	11.2	16.2	21.4	25.2	22.7	17.6	14.4	7.7	3.9	12.7
Najaf	5.5	7.6	11.7	17.7	23.1	26.9	28.9	28.4	24.7	19.6	12.2	7.2	17.8
Khales	4.2	5.6	9.2	14.2	18.9	22.4	24.6	24.0	19.9	15.9	9.1	5.3	14.5
Baghdad	4.2	5.9	10.0	15.6	20.6	23.8	25.9	25.3	21.2	16.5	9.8	5.6	15.4
Al-Hella	4.5	6.2	10.1	15.1	20.0	23.1	24.7	24.7	21.3	17.2	10.4	6.5	15.31
Al-Diwaniyah	5.8	7.9	11.9	17.7	23.2	25.7	27.6	27.0	23.9	19.5	12.4	7.7	17.5
Al-Hay	6.7	8.5	12.5	18.1	24.2	27.6	29.4	28.9	25.1	20.2	12.9	8.5	18.6
Al-Samawa	5.7	7.6	11.8	17.6	23.3	26.1	27.8	27.1	23.6	18.9	12.3	7.5	17.5
Al-Amara	6.5	8.4	12.4	18.1	23.9	27.2	29.1	28.4	24.2	19.1	12.6	7.9	18.2
Al-Nasiriyah	6.4	8.4	12.7	18.8	24.0	26.7	28.6	28.3	24.6	19.8	12.8	7.9	18.3
Al-Basra	7.8	9.6	13.9	19.9	25.6	27.9	29.6	28.8	25.2	20.8	14.1	9.2	19.4
Al-Rutba	2.4	3.6	7.2	12.0	16.7	21.0	23.4	23.5	20.1	16.1	9.5	4.3	13.3

the central part of the country (the river plain) [24]. Iraq can be divided into the following agroecological zones:

- *Arid lowland region*: This area represents the areas with a long summer season of about 9 months and the rate of rainfall in these areas more than 200 mm in winter. These areas are characterized by hot summers (extreme temperatures sometimes exceeding 43 °C).The winter season extends for 2 months. The temperatures in the coldest days of winter are around 4 °C. The appearance of dust storms is common in the summer and some heat waves that raise the temperature to 50 °C. During the winter some cold waves occur where temperatures drop to −8 °C. In general the humidity is low except in the southern region near the sea. Evaporation of free water surfaces up to 10 mm per day and annual evaporation of about 2100 mm [25].
- *Semiarid lowland region*: This area includes the hills in the northeast with a rainfall between 200 mm and 400 mm. In this region, the summer is hot and dry with a maximum temperature of 43 °C, and the maximum temperature recorded in the past years reached 49 °C. The minimum temperatures range between 30 °C and 32 °C. Winter in this region is moderate, and the minimum temperature reaches 1 °C, and the maximum temperature is 14 °C. The lowest temperatures recorded in December and January were around −11 °C. Rain falls during winter and spring in November to April, but there is a huge disparity in quantities and seasons from year to year. Relative humidity in these areas is between 12% and 15%. In summer, high winds are common in these areas [26].
- *Sub-humid upland and mountain region*: This area includes the area of the Zagros Mountains within the borders of Iraq and some valleys as well as part of the foothill area. The main annual rainfall ranges from 400 mm to 1100 mm. The summer of these areas is hot, and the winter is cold. The highest months of the year are the months of July and August, with the average temperature reaching 43 °C and sometimes rising during the heat waves to 50 °C. The average temperature for the month of July is about 22 °C. In the winter, the monthly lowest temperature in the coldest days of January reaches 10 °C, and the minimum temperature recorded in this area was −11 °C [27].
- *Hot subtropical desert region*: This region has a warm subtropical climate. In very cold winter, frosts occur, and temperatures are low enough. In summer, temperatures are high enough. Relative humidity varies from absolute desert to Mediterranean desert [28].
- *Subtropical Mediterranean region*: This region is characterized by subtropical temperatures. During winter, frost occurs, and the temperatures are low enough. In summer, the atmosphere is hot enough but not too hot. The humidity in this region is similar to that of the wet Mediterranean regions [29].

Iraq is strongly affected by high subtropical pressure in summer and winter because it is affected by the low-pressure system that runs through Iraq from west to east and determines rainfall and snow in mountainous areas in the north. The high air pressure migrates north in the summer and shows its direct effects on the desert areas across North Africa and the Arabian Peninsula [30]. In the winter, periodic low-pressure systems are the dominant. High and low meteorological pressures determine wind movement, which is an important climatic variable in the northern region. For most of Iraq, the Al-Shamal wind (the Arabic translation of north) is the predominant wind pattern. Very dry air is caused by wind from the north and northwest and spreads across the entire country and inhibits cloud growth and thus reduces rainfall throughout the year. In the summer months, the average daily wind speed is higher than 10 knots causing the rise of dust and sometimes causes sandstorms. Weather conditions in winter cause the winds to be faster but often repeated much less [31]. The Al-Shamal winds dominate most of Iraq, and at a speed of about eight to ten knots on average, although much faster wind speeds were registered sometimes, as the wind speed exceeds 50 knots locally. Al-Shamal winds are the dominant in the winter and are characterized by speeds of 25–30 knots, blowing from the north or northwest. Al-Shamal winds cause dust and sandstorms, which are relatively common in Iraq and occur two or three times a month in winter. On the other hand, Al-Shamal which blows for a continuous period of 3 to 5 days is linked to the suspension of pressure systems on the Strait of Hormuz, leading to higher pressure from the north and low pressure on the Arabian Gulf. This wind system is the most formed but with a frequency less than a few times during the winter season. From these Al-Shamal winds, severe sandstorms are generated when winds reach 25 knots for several days [31].

In the beginning of the summer and winter seasons, there is a different wind system called Al-Sharki in Iraq, which means the eastern wind in Arabic. The wind, which is humid, blows from the south or southeast and is popular in June, which is usually the worst month of the year due to the frequency of Al-Sharki and Al-Shamal winds in central Iraq. Al-Sharki winds are associated with the passage of low-pressure systems over the country. They are warm winds, and dry air moves before the front. Table 2.5 represents the monthly and yearly rates for wind velocities. Table 2.6 gives the percentages of the repetition of the governing wind. Table 2.7 illustrates the humidity distribution in Iraq for the period from 1982 to 2013 [32, 33].

All these variable meteorological conditions make Iraq exposed to a variety of climatic or weather hazards such as:

2.3.1 Drought

Iraq suffered from continuous drought during the period from 1984 to 1990, and the same was repeated in 1999/2000. Currently, environmental conditions have improved somewhat. That drought is a major concern for the people of Iraq. Iraq is an agricultural country, and the importance of water for agriculture cannot be denied. Drought also affects the hydrological conditions of the Euphrates and Tigris rivers, which are fully dependent on irrigation. It also reduces rain-fed agriculture and cultivated areas year after year. Drought is associated with the impact of low-pressure systems migrating from Europe and high-pressure systems coming

Table 2.5 The monthly and yearly rates for the wind velocity (m/s) for Iraqi stations for the period 1982–2013

Station	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec	The average
Sulaymaniyah	1.5	1.9	2.4	1.8	2.2	2.6	2.7	2.4	1.6	1.7	1.7	1.3	1.98
Arbil	2.7	3.3	3.3	2.9	3.4	2.9	2.8	2.6	2.5	2.8	2.3	2.1	2.8
Kirkuk	1.9	1.6	1.8	1.9	2.2	2.1	1.9	1.8	1.5	1.6	1.3	1.2	1.7
Mosul	1.2	1.3	1.4	1.6	1.9	1.8	1.7	1.5	1.2	1.0	1.0	1.0	1.4
Najaf	1.3	1.8	2.1	2.2	2.2	2.9	2.8	2.3	1.7	1.4	1.2	1.1	1.9
Khales	2.2	2.8	3.0	2.9	2.7	3.2	2.9	2.7	2.1	1.7	1.7	1.9	2.5
Baghdad	2.6	2.9	3.2	3.2	3.3	3.8	4.0	3.5	2.8	2.6	2.5	2.4	3.1
Al-Hella	1.4	1.8	2.2	1.9	2.0	2.4	2.6	2.0	1.5	1.2	1.1	1.3	1.8
Al-Diwaniyah	2.5	2.7	3.0	3.2	2.9	3.5	3.6	2.8	2.2	2.0	1.9	2.1	2.7
Al-Hay	3.5	4.2	4.1	4.2	4.4	5.5	5.6	5.1	4.3	3.6	3.7	3.4	4.3
Al-Samawa	2.6	3.1	3.4	3.6	3.5	3.8	3.9	3.4	3.0	2.7	2.4	2.5	3.2
Al-Amara	2.8	3.3	3.8	3.8	4.1	5.7	5.6	5.1	3.9	3.1	3.0	2.7	3.9
Al-Nasiriyah	3.3	3.8	4.1	4.4	4.6	5.9	5.9	5.1	4.1	3.4	3.2	3.1	4.3
Al-Basra	3.1	3.5	3.6	3.8	4.1	5.2	5.3	4.6	3.7	2.9	3.1	3.0	3.8
Al-Rutba	2.4	3.1	3.2	3.1	2.9	3.0	3.4	2.7	1.8	1.9	1.8	2.03	2.60

Table 2.6 The percentage of the repetition of the governing wind direction for Iraqi stations (day/year) for the period from 1982 to 2013

	The governing wind direction								
Station	NE	E	SE	S	SW	W	NW	N	Calm
Sulaymaniyah	14	7	8.7	12.7	3.9	10.1	3.6	7.9	32.1
Arbil	4.0	14.9	8.4	7.9	8.8	10.4	4.9	4.3	36.4
Kirkuk	10.7	6.1	4.9	4.5	2.4	13.3	4.8	4.7	48.6
Mosul	4.6	9.3	5.1	6.3	2.1	18.9	13.6	13.5	26.6
Najaf	3.9	3.3	5.3	2.7	2.9	7.8	25.3	35.3	13.5
Khales	2.8	0.9	1.9	9.8	6.3	11.0	35.2	8.2	23.9
Baghdad	9.1	5.2	3.5	2.3	3.8	16.6	31.4	13.8	14.3
Al-Hella	0.4	0.9	0.6	1.0	9.2	5.3	35.1	33.7	13.8
Al-Diwaniyah	1.9	0.4	5.6	2.1	8.3	1.7	40.3	27.1	12.6
Al-Hay	2.1	6.6	4.4	2.4	1.7	21.2	37.9	9.1	14.6
Al-Samawa	1.1	4.4	2.1	3.0	1.0	10.7	56.5	5.8	15.4
Al-Amara	1	2.8	0.7	2.5	2.4	11.8	37.4	30.9	10.5
Al-Nasiriyah	1.0	2.1	1.3	0.8	3.1	8.1	53.9	21.5	8.2
Al-Basra	1.9	5.1	3.0	1.4	2.2	12.1	60.0	5.3	9.0
Al-Rutba	4.4	5.0	5.5	7.2	9.0	22.1	20.2	9.3	17.3

from Siberia during the winter months. The low rainfall during the rainy season in winter and spring is strongly related to the high-pressure system coming from Siberia. The stronger this Siberian high pressure, the lower the impact of the western depression and the arrival of the internal areas of Iraq more difficult [34, 35].

2.3.2 *Flooding*

Floods are a potential risk during two season (winter and spring) periods. Every year, flooding is expected in the Tigris and Euphrates valley during spring due to the melting of snow and increased rainfall each year. The amount of snow falling in the northern highlands and the intensity and duration of spring rainfall in the northern half of the country determine the extent of these floods. The timing of this event varies from year to year, but it is expected to occur in March or April, the most humid months of the year. The possibility of a temporary and limited-time flooding can be achieved at much shorter intervals and pose a separate risk and occur in winter and spring. Such flooding can be predicted and may occur anywhere, usually lasting a few hours (Fig. 2.6) [36].

Table 2.7 The monthly and yearly rates for the relative humidity (%) for Iraqi stations for the period 1982–2013

Station	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec	The average
Sulaymaniyah	75	69	58	55	43	26	23	22	25	39	58	68	46.8
Arbil	71.5	68.5	59	55.5	38.2	25.4	24	25.5	29.1	41	56.1	67.1	46.7
Kirkuk	71.9	67.3	58.5	51.1	34.7	24.9	23.2	24.4	27.7	39.4	58.1	69.4	45.9
Mosul	78.8	73.4	67.5	59.9	43.4	28.0	25.4	26.8	31.5	45.7	64.6	78.0	51.9
Najaf	48.4	45.6	35.1	30.0	22.6	17.9	16.2	16.9	21.1	29.2	39.2	48.2	30.87
Khales	76.8	67.7	58.3	52.6	41.0	33.9	34.0	35.1	40.2	47.2	65.4	74.6	52.2
Baghdad	71.2	57.3	50.4	43.6	31.7	25.1	24.7	26.7	31.8	42.1	57.8	69.3	44.3
Al-Hella	67.5	58.6	48.8	44.9	34.9	29.9	29.7	31.9	35.9	46.9	58.4	67.2	46.3
Al-Diwaniyah	68.2	58.9	49.9	38.7	31.4	27.0	27.0	29.3	31.5	41.3	57.2	67.0	43.9
Al-Hay	70.9	61.6	54.2	45.3	33.0	25.3	23.9	24.8	28.4	39.1	55.5	67.9	44.7
Al-Samawa	65.6	57.8	48.4	39.2	28.3	23.4	22.3	23.9	27.6	37.3	53.1	61	40.7
Al-Amara	72.0	63.6	56.5	46.9	34.7	25.7	24.0	25.8	29.3	41.3	58.4	67.2	45.5
Al-Nasiriyah	68.0	58.7	48.9	41.8	30.8	22.7	21.6	23.3	27.5	38.3	54.3	66.1	41.8
Al-Basra	68.3	57.7	47.3	38.7	28.5	22.4	22.5	24.5	27.8	39.4	54.3	66.3	41.5
Al-Rutba	69.8	60.1	52.6	43.3	34.6	29.5	28.0	28.7	31.8	43.7	56.5	69.2	45.6

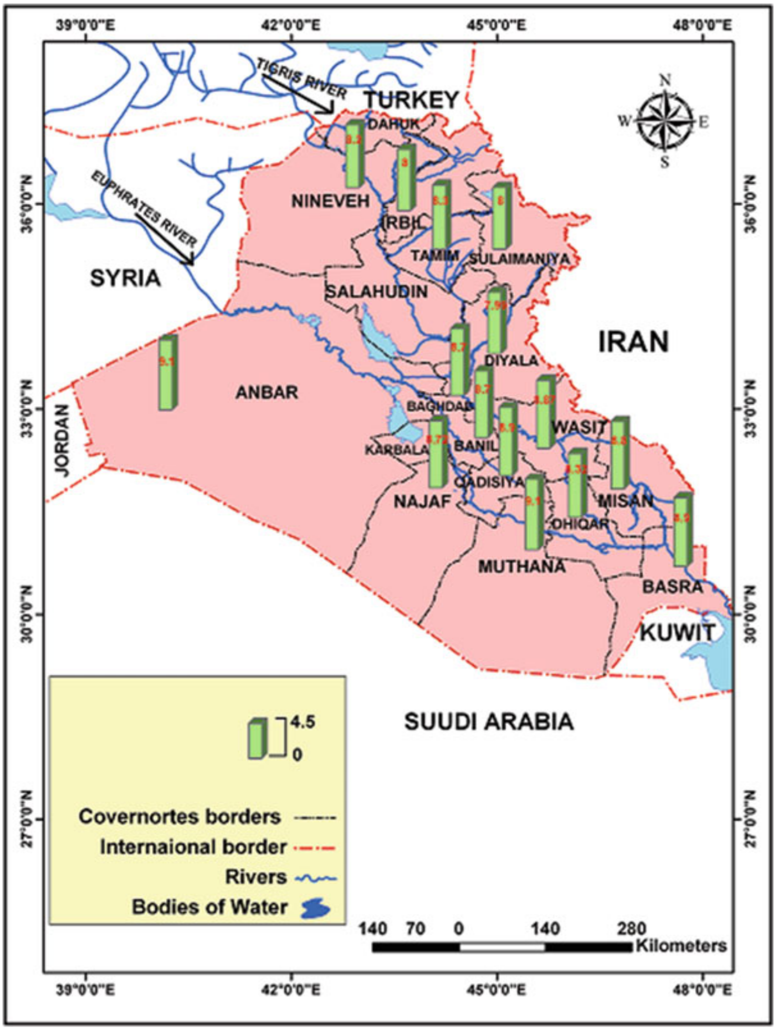

Fig. 2.6 Water body distribution on Iraq area

2.3.3 Dust Storms

The risk of dust storms comes from the availability of dry and fragmented soil that is not coherent, with high-speed winds during the year. Dust and sandstorms are an imminent danger throughout Iraq, and its causes must be addressed. The presence of poor vegetation in the southern deserts, in addition to the severe decrease in the supply of silt, causes the increase of sand. Even in Iraq's high-humidity areas, adjacent to the Euphrates and Tigers rivers, the soil fragmentation and drought have become a problem due to poor irrigation practices, causing desertification to increase on the expense of agricultural land [37]. Dust storms are clear evidence of soil fragmentation and erosion and the high level of desertification in the country. When the dust storm rises above, very tiny particles remain suspended in the air as airborne and transported for long distances. Larger particles are deposited faster. This phenomenon causes the local movement of sand dunes that go beyond agricultural land and pastures. The occurrence of sandstorms can be considered a phenomenon that represents the final stage of the desertification process [38, 39].

Iraq has suffered three devastating wars in two decades, in addition to drought, causing a new dust bowl. Now, a large part of the irrigation water is being lost by Iraq to the benefit of its neighbors in the highlands of Turkey, Syria, and Iran, as well as land from overgrazing and plowing. The decrease in the rate of water flowing into the river and the drying of the marshes (the stupid step taken by the Baath government in 1988) caused the deterioration of the irrigation infrastructure, the shrinking of the irrigated area, and the increase of the dry lands in Iraq. As a result, the Fertile Crescent, the cradle of civilization, turned into a dust bowl [40]. Dust storms occur with an unprecedented frequency in the last century. In July 2009, a dust storm lasted for several days in what was described as the worst storm in Iraq throughout its history. This storm headed east to Iran and caused the closure of government offices, private offices, schools, and factories. In spite of all this, this new bowl is still small compared to the dusty containers in northwest China and Central Africa (Sahara). However, this does not prevent this new development from disturbing Iraq and its neighbors [41].

2.4 Iraq Electricity Conditions

Electricity entered Iraq in 1917 as it erected the first electric machine in the building “Khan Dallah.” It was a limited electrical power diesel engine of 200 VDC (DC) each. Diesel engines were installed after that in different parts of Baghdad City, including Al-Sarai area to enlighten Al-Serail and Al-Qishleh buildings, Sariat Al-Majidiyah to illuminate the hospitals in the Bab Al-Moatham, and Karada Mariam to flare camps as Sl-Huneidi and Al-Rasheed camp later. In the same year (1917), the first street in the city of Baghdad, “Al-Rasheed Street,” was lighted. In 1918 the authorities at that time worked to enlighten the buildings and homes for the people who ask for electricity. The demand of electric power increased, while the distribution ability was limited for a certain amount [42].

The competent authorities of the then erected three steam engine units with 3.3 KV generating power each generated alternating current (AC) in Alqatr terminal, and the wires were extended under the ground. Many switching equipment were monument in each of the Alaboukhanh and Al-Majidiyah hospital to feed consumers who were using DC (+400) volts to alter the power lines to AC 3.3 KV lines. The network of Baghdad was enlarged by transport electricity to the other side of

Baghdad (Al-Karkh) by passing the wires by cables under water (near the Al-Shohadaa Bridge) [43].

In 1927, columns were erected to carry the electrical wiring for lighting the streets of Al-Jaafyr and Allawi Hilla. In 1931, the Sharafiya station was established. This station was initiated using two Swiss-made Brown Boveri generators with a power of 2.5 MW each. The station was consisted of two boilers in the first and second terminal. And it was opened on Monday, the first of May 1933. In 1937 a third unit was erected; it was English-made (Parson) with "5" MW power with the third boiler. The fourth Swiss-made (Brown Boveri) unit with capacity of 60 MW was established, and the fifth and sixth units were English-made (Parson) with the capacity of 12 and 5 MW through 1950–1952. The overall capacity of the plant in 1955 reached 41 MW [41].

In 1955, the enlightenment company was nationalized, and the limited wattage of the city of Baghdad was called for the first of October as Baghdad power station. This station was associated with the Ministry of Communications and Works. In 1958, the National Electricity Board was established, which took over the possession and operation of all the generating stations and transmission lines and substations that were constructed by the Board of Reconstruction established [44].

In 1964, Baghdad Electricity Enterprise was merged with the National Electricity Enterprise, and both were replaced by the Baghdad Electricity Department. In 1975, the Public Electricity Corporation was established to include all varieties of electricity. In 1987, the Public Electricity Corporation was canceled and became the General Establishment for Electricity Distribution, Baghdad Chamber of the Ministry of Industry and Minerals. In 1999, the Electricity Authority was established. In 2003, the Ministry of Electricity was established [45].

After 2003, and after the unjust blockade by the United Nations on Iraq was stopped, Iraq was able to export oil without limitations. Also, there was a rise in world oil prices; all of this caused a high level of income of the Iraqi people. The incomes rising caused an increase of the electricity consumption for home appliances and fuel due to the rapid growth of the fleet of vehicles and industry. It is crucial to catch up and keep pace with the growing demand for electricity for the Iraq National Development. A lack in electricity supplies can be seen, and it is the main obstacle to development in Iraq. Today, the stations produce electricity power more than ever, but electricity services are still inadequate to meet the need. The cutoff of the power supply is a daily basis, and the use for diesel backup generators on a large scale is a necessity. The construction of modern electrical systems with abilities to generate and supply enough electrical power is an immediate priority. Iraq needs additional power counted for more than 70% of the net electricity generation capacity today to meet the demand in full. With the exception of hydroelectric power, the use of renewable energy sources is very limited or nonexistent and without the potential of Iraq [46].

In spite of the large increase in electrical capacity in the last few years (the height of the net daily production in 2011 was about 70% higher than in 2006), it is still far from sufficient to meet demand. The net available energy at its peak in 2011 was about 8 GW while the estimated net capacity needed to meet the peak demand exceeded 15 GW, resulting in the need for about 7 GW more than the capacity available (an increase of about 70%). This is before taking into account the increase in demand, which is likely to happen when the power supply becomes more reliable. The immediate priority for the electricity sector in Iraq is to build additional generating capacity and ensure that it has adequate supplies of fuel. The last part must be easy for Iraq because it is an oil-producing country [47, 48].

About 90% of the Iraqi families depend partly on their own generators in an attempt to fill some of the gap between supply and demand of electricity. The private generators mean either the family generator or the common generator working on the neighborhood level. The generated electricity from these sources is difficult to quantify, but it can be estimated that in 2011 the common generators in central Baghdad alone produce what worth 3 terawatts compared to 37 terawatts for the consumption of which came from the network. A 2009 study estimated that about 900 megawatts were produced by private generators. The private generators currently play an important role in reducing the electricity supply deficit, as well as given the flexibility to provide electricity access to rural areas [11, 49]. However, despite the common generators receiving a government fuel support, they provide to consumers supplies much higher than the electricity network on some days. The citizens of the neighborhoods are paying electricity by 10 to 15 times more from the owners of these generators. This contributes to diesel generators increasing the local air pollution significantly, as well as being a costly method of processing power. In 2011, even with the use of private generators, fitted average electricity to end users was limited by about 11–19 h a day (from all sources) with varying amounts across the country [50, 51].

The weather conditions add an additional challenge for Iraq, as the electricity demand is seasonal with peak value in the summer months, due to rising temperatures in most parts of the country. During the summer, peak demand for electricity can be expected to reach levels around 50% above the average level of demand, thereby, increasing the gap between the network electricity supply (which operates at maximum capacity) and the demand [52, 53].

The existing generation and distribution of electricity infrastructures need the rehabilitation and modernization, as well as rapid expansion, to be able to meet the growing demand for electricity. More than 47% additional capacity was added since 2000, which is equal to more than half the nominal generation capacity before 1990. The recent increased production capacity to improve the overall efficiency of the sector has helped, but it is still required less than the required and less than the international standard level, also [55]. The constant and major concern in the electricity sector in Iraq is to meet the demand for power generation with reliable and continuous supply [54, 55].

Iraq has very good solar resources. Despite the best solar radiation in the Middle East is in the far south (in Saudi Arabia and Yemen), for example, the average solar radiation in Iraq is similar to that in North Africa. Iraq also has some history of research in solar energy (which was reduced dramatically during the decades of wars and sanctions) [56]. Today, solar research activities are sponsored by the Ministry of Higher Education and Scientific Research, the Ministry of Electricity, and the

Ministry of Science and Technology. Many research projects are being implemented by the Iraqi government university groups, such as the preparation of solar radiation data, a project to provide telecommunications stations in remote areas using solar energy, and a feasibility study for the application of PV systems for pumping water from wells to cultivate remote areas [57].

References

1. Bernhardsson MT (2005) Reclaiming a plundered past: archaeology and nation building in modern Iraq. University of Texas Press, p 97. ISBN 978-0-292-70947-8
2. Kazem AA, Chaichan MT, Kazem HA (2014) Effect of dust on photovoltaic utilization in Iraq: review article. Renew Sust Energ Rev 37:734–749
3. UN Public Information Office (UNPIO) (2013) www.iq.one.un.org. Accessed on May 2013
4. Federal Research Division (FRD), Library of Congress (2006) Country profile: Iraq. www.lcweb2.loc.gov. Accessed on May 2013
5. Britannica Online (2009) Tigris-Euphrates river system: physical features. www.britannica.com
6. /http://www.arab.de/arabinfo/iraq.htmS
7. Hasoon AF, Rashed EK, Muzan AA (2013) Population growth and its effect on temperature increase for some meteorological stations in Iraq. Eng Technol J 31(2):25–39
8. /http://www.fao.org/ag/agl/aglw/aquastat/countries/iraq/index.stmS
9. Kazem HA (2011) Renewable energy in Oman: status and future prospects. Renew Sust Energ Rev 15:3465–3469
10. Chaichan MT, Kazem HA (2011) Thermal storage comparison for variable basement kinds of a solar chimney prototype in Baghdad-Iraq weathers. Int J Appl Sci (IJAS) 2(2):12–20
11. Kazem HA, Chaichan MT (2012) Status and future prospects of renewable energy in Iraq. Renew Sust Energ Rev 16(8):6007–6012
12. Government of Iraq Ministry of Electricity; Government of Iraq budget figures, cited in Centre for Strategic and International Studies, Iraq after the election: meeting the challenges of 2010, Presentation July 2010
13. IKN (Iraq Knowledge Network Survey 2011) (2012) Iraq Central Statistics Organization/Kurdistan Region Statistics Organization/United Nations, Baghdad
14. Al-Taei, Samer AR (2010) Two dimensional oil spill model for simulating the movement and fate of oil slicks in the North West Arabian Gulf. Ph.D. thesis, College of Education, University of Basrah
15. United Nation Environment Programme, United Nation in Iraq (2007) Post-conflict assessment, clean-up and reconstruction, Job No.: DEP/1035/GE, ISBN: 978-92-807-2906-1
16. Hameed H, Aljorany YS (2011) Investigation on nutrient behavior along Shatt Al-Arab River, Basrah, Iraq. J Appl Sci Res 7:1340–1345
17. Yaseen BR, Al Asaady KA, Kazem AA, Chaichan MT (2016) Environmental impacts of salt tide in Shatt al-Arab-Basra/Iraq. IOSR J Environ Sci Toxicol Food Technol 10(1–2):35–43
18. FAO (2004) Fishery and aquaculture country profiles, Iraq. http://www.fao.org/fishery/countrysector/FI-CP_IQ/3/en
19. Salman SD, Marina BA, Ali MH Oshana VK (1986) Zooplankton studies. In final report the 18-month marina pollution monitoring and research programming in Iraq. Marine Science Centre of Basrah University, Basrah, pp 156–166
20. CIMI (2010) Managing for change: the present and future state of the Iraqi Marshes, Canada-Iraq Marshlands Initiative
21. Al-Waeely AA, Salman SD, Abdol-Reza WK, Chaichan MT, Kazem HA, Al-Jibori HSS (2014) Evaluation of the spatial distribution of shared electrical generators and their environmental effects at Al-Sader City-Baghdad-Iraq. Int J Eng Technol IJET-IJENS 14(2):16–23

22. Kelley J (2004) Trip report: collection of soil samples from Iraq, March and April 2004. ERDC, Engineering Geology and Geophysics Branch, Vicksburg, pp 11
23. Anderson J (2004) An analysis of a dust storm impacting operation Iraqi Freedom, 25–27 March 2003, MSc Thesis, Dept of Meteorology, Naval Postgraduate School, p 123
24. UNICEF (2010) Environmental survey in Iraq for the year (water-sewage-municipality services) summary report. Republic of Iraq and European Union
25. Brinckerhoff P (2009) Master plan for the KRG Electricity Sector. Parsons Brinckerhoff, Erbil
26. Lansel S (2010) Technology and future of III-V multi-junction solar cells. Iraqi J Appl Phys 6 (3):3–8
27. King WC, Palka EJ, Anderson PG, Cowher DD, Dalton JB, Gloede JSW, Herl BK, Lahood AA, Lohman AD, Mangin PE, Malinowski GC, Pannell RP, Sampson MR, Thompson WC (1996) In: Malinowski JC (ed) Iraq: a geography. Department of Geography & Environmental Engineering United States Military Academy, West Point/New York
28. Ali FA (2011) Computation of solar radiation on horizontal surface over some Iraqi cities. Eng Technol J 29(10):2026–2043
29. Mutlak FA (2011) Design and fabrication of parabolic trough solar collector for thermal energy applications, Ph D Thesis, Collage of Science, Baghdad University, Iraq
30. NASA (2008) Surface meteorology and solar energy – available table. Atmospheric science Data Center. Available at: https://eosweb.larc.nasa.gov/sse/
31. Omer TMA (2011) Country pasture/forage resource profile. FAO. Available at: http://www.fao.org/Ag/Agp/Agpc/Doc/Counprof/PDF%20files/iraq.pdf
32. CIA world fact book (2003). Available at: https://www.cia.gov/news-information/press-releases-statements/press-release-archive-2003/pr08122003.htm
33. National Geographic Geography shapes nature of war in Iraq March 2003. Available at: https://news.nationalgeographic.com/news/2003/03/0327_030327_wargeography.htm
34. El-Kuwaz S (2007) Rangelands Management and Development in Iraq, Proceedings of the expert consultation on range monitoring including under forest systems in the Near East. FAO, Rome, pp 177–188
35. Directorate General of Horticulture, Forests and Rangelands, Conference on the Strategic Plan for the Ministry of Agriculture (2007)
36. National Oceanic and Atmospheric Administration, Climate Information Project, 2000 Archive of Climate-Weather Impacts (2000)
37. Akanda A, Freeman S, Placht M (2007) The Tigris-Euphrates river basin: mediating a path towards regional water stability, The Fletcher School – Al Nakhlah – Tufts University
38. Schnepf R (2003) Iraq's agriculture: background and status, congressional research service. The Library of Congress. Available at: https://digital.library.unt.edu/ark:/67531/metacrs7073/m1/1/high_res_d/RS21516_2003May13.pdf
39. Badry MM, Mehdi MS, Khawar JM (1979) Water resources in Iraq. In: Johl SS (ed) A joint publication of ECWA, FAO and the Foundation for Scientific Research of Iraq. Pergamon Press
40. FAO (2003) Towards sustainable agricultural development in Iraq: the transition from relief, rehabilitation and reconstruction to development. Available at: http://agris.fao.org/agris-search/search.do?recordID=XF2008434245
41. Howard V, Goode's world atlas (2000) 20th edn. Rand McNally. ISBN-13: 978-0528853395. ISBN-10: 0528853392
42. Air Force Combat Climatology Center (AFCCC) (1995) Operational Climatic Data Summary for Iraq
43. National Oceanic and Atmospheric Administration (NOAA) (2000) Climate Information Project, Archive of Climate-Weather Impacts
44. Wiley T (2002) In: Malinowski J (ed) Iraq: a regional geography, country map, location. US Military Academy Press, West Point
45. Brown LR (2011) World on the edge: how to prevent environmental and economic collapse. Institute, Earth Policy

46. History of Electricity. Iraqi Ministry of Electricity, p. 14, Retrieved in 31 December 2008. Available at: http://www.wiki30.com/wa?s=Electricity_sector_in_Iraq
47. Progress Amid Chaos, Taymor Farage, National Petroleum Services Co. Ltd. T&D World Magazine, (2008, 1 June). Available at: http://www.tdworld.com/overhead_distribution/progress_amid_chaos/
48. World Energy Outlook Special Report, Iraq Energy Outlook (2012, 9 October). Available at: https://www.iea.org/publications/freepublications/publication/WEO_2012_Iraq_Energy_OutlookFINAL.pdf
49. Ministry of Planning- Republic of Iraq (MOP) (2010) National Development Plan for the Years 2010–2014, Ministry of Planning of Iraq, Baghdad. Available at: http://www.unesco.org/education/edurights/media/docs/795ff8cb2cd3987aba07572026cdb6d0958cd27a.pdf
50. Arab Union of Electricity (AUOE) (2010) Statistical Bulletin 2010, Issue 19, Arab Union of Electricity, Amman, Jordan
51. IKN (Iraq Knowledge Network) (2012) Iraq Knowledge Network Survey 2011, Iraq Central Statistics Organization/Kurdistan Region Statistics Organization/United Nations, Baghdad
52. Brinckerhoff P (2009a) Masterplan for the KRG Electricity Sector, Parsons Brinckerhoff, Erbil, Iraq
53. Brinckerhoff P (2009b) Final report on the survey of private generation in the Baghdad Governorate. Parsons Brinckerhoff, Baghdad
54. Brinckerhoff P (2010) Iraq electricity master plan. Parsons Brinckerhoff, Baghdad
55. Iraq Central Statistics Organization (ICSO) (2012) Annual abstract of statistics 2010–2011, Central Statistics Organization, Baghdad
56. El-khayat MM (2005) Solar energy conservation and photo energy systems: renewable energy potential in the Arab region
57. Landis GA (1997) Mars dust removal technology, NASA Lewis Research center, IEEE, Energy Conversion Engineering Conference 1:764–767

Chapter 3
Status of Renewable Energy in Iraq

3.1 Introduction

Due to the increase in the population and the increase in demand for energy in general and electric power in particular in addition to the fluctuation of oil prices accompanied by the possibility of depletion and increase the complaint of the impact of emissions from the burning of fossil fuels, all eyes for serious and direct thinking in the use of renewable energies, especially solar and wind that can be used in generating electricity in huge capacities [1–4].

Iraq, a member of the Organization of the Petroleum Exporting Countries (OPEC), covers more than 430,000 square kilometers, although the exact figure varies from one source to another. This disparity depends, for example, on whether all land and water are included. Iraq has a coastline of only 58 kilometers along the Arabian Gulf coast (see Fig. 3.1) [5]. Four major geographical regions have been recognized [6–9]. They are briefly described as follows:

- The northeast highlands: Covering these highlands up to 20% of Iraq's territory and extending south of the Mosul-Kirkuk line northward to the southern Turkish and northern Iranian borders. These highlands are mountain ranges up to 3600 meters high.
- The desert plateau: Wide plain and scattered areas of sand representing about 40% of the territory of Iraq and located in the west and southwest of the Euphrates river. In this area there is a network of watercourses that are seasonally formed in the valleys near the Euphrates river border.
- Highlands: Is a transitional area located between the desert plateau and highlands and is located between the Euphrates north of the Tigris and Tigris north of Samarra. This region is part of the natural area representing the extension of the composition that extends from Turkey and Syria. This area represents about 10 percent of Iraq's territory.

M. T. Chaichan, H. A. Kazem, *Generating Electricity Using Photovoltaic Solar Plants in Iraq*, https://doi.org/10.1007/978-3-319-75031-6_3

Fig. 3.1 Map of Iraq and border nations (From: www.cia.gov on 17 December 2011)

- The Gharini plain: This plain is formed as a delta produced by the Gharin Tigris and Euphrates rivers for thousands of years and represent about 30% of the territory of Iraq. This area starts north of Baghdad and extends to the Gulf.

The population of Iraq is in the rise and has increased from 14 million in 1980 to 32 million in 2010. As the population continued to increase at this pace, it is expected to increase to about 64 million in 2050 [10]. The actual density of the population varies from the western desert region of Anbar province, where the distribution of the population to the area of 5 inhabitants/km^2, escalating this distribution in the fertile lowlands in the province of Babylon to more than 170 inhabitants/km^2. Most of the population is concentrated (almost 75% of the population) in urban centers (cities) [11]. The population growth rate in Iraq rose from 2.75% in 1980–1985 to 3.23% in 1995–2000, and then it declined to 2.72% in 2000–2005. This rate is expected to reach 1.09% in 2045–2050 [12].

There are many raw materials available in Iraq from multiple geographical sources. Most of them have wide geologic distribution that allows for a degree of flexibility in site selection. There are many raw materials still not exploited optimally. Oil is the most important raw material on which the Iraqi government's budget depends. Iraq's oil reserves are estimated at 115 billion barrels. Undiscovered oil reserves are more than stable, so Iraq is the second largest reserve in the world after Saudi Arabia. These estimates indicate that the Iraqi oil reserves up to 300 billion barrels. Oil production in 2009 amounts to 2,399,000 b/d as shown in Fig. 3.2a.

Natural gas is currently burned directly in Iraq because of its exits naturally with oil, yet it can be considered the second important raw materials if it was used wisely.

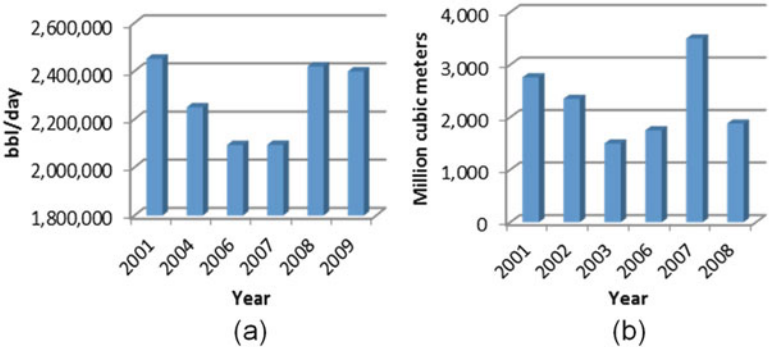

Fig. 3.2 Production of (**a**) oil and (**b**) natural gas

Natural gas can revive the Iraqi economy. The fixed reserves of Iraqi gas are about 1.3 trillion cubic meters, which means that Iraq has 8.1% of the world's fixed reserves of natural gas. Iraq occupies the tenth position in the world among countries rich in natural gas with this level of reserves. There are many other raw materials such as sulfur, phosphate, and white clay, but they have less importance and their share in the Iraqi economy is very low. Natural gas production in 2009 was 1,880,000,000 m^3 as shown in Fig. 3.2b [12].

In Iraq the problem does not exist in finding new resources of energy because it is considered one of the richest oil countries [13]. But Iraq suffers from the growing shortage in fulfilling the demand on electrical energy due to increasing rise in demand levels (see Fig. 3.3). The electrical power generation stations fail to comply with it because of its limited production capacities and plenty defects due to its oldness. In recent days thinking aimed towered renewable energy and specifically solar energy as most nation did [12].

3.2 Renewable Energies in Iraq

Iraq's geographical location has largely determined the climatic conditions in most parts of the country with desert climate. It is very dry, cold in winter, and very hot in summer, with little rain falling in the winter season [14]. The proximity of the location of Iraq from the countries of the solar belt makes it receive high intensity of radiation sufficient to run solar plants to generate electricity in an excellent manner. Iraq also has a number of specifications that make it possible to use other types of renewable energies in variable regions of the country to produce electricity [15]. In the coming paragraphs, we will briefly outline the renewable energies in Iraq and the possibilities of benefiting from them to produce electricity commercially [16].

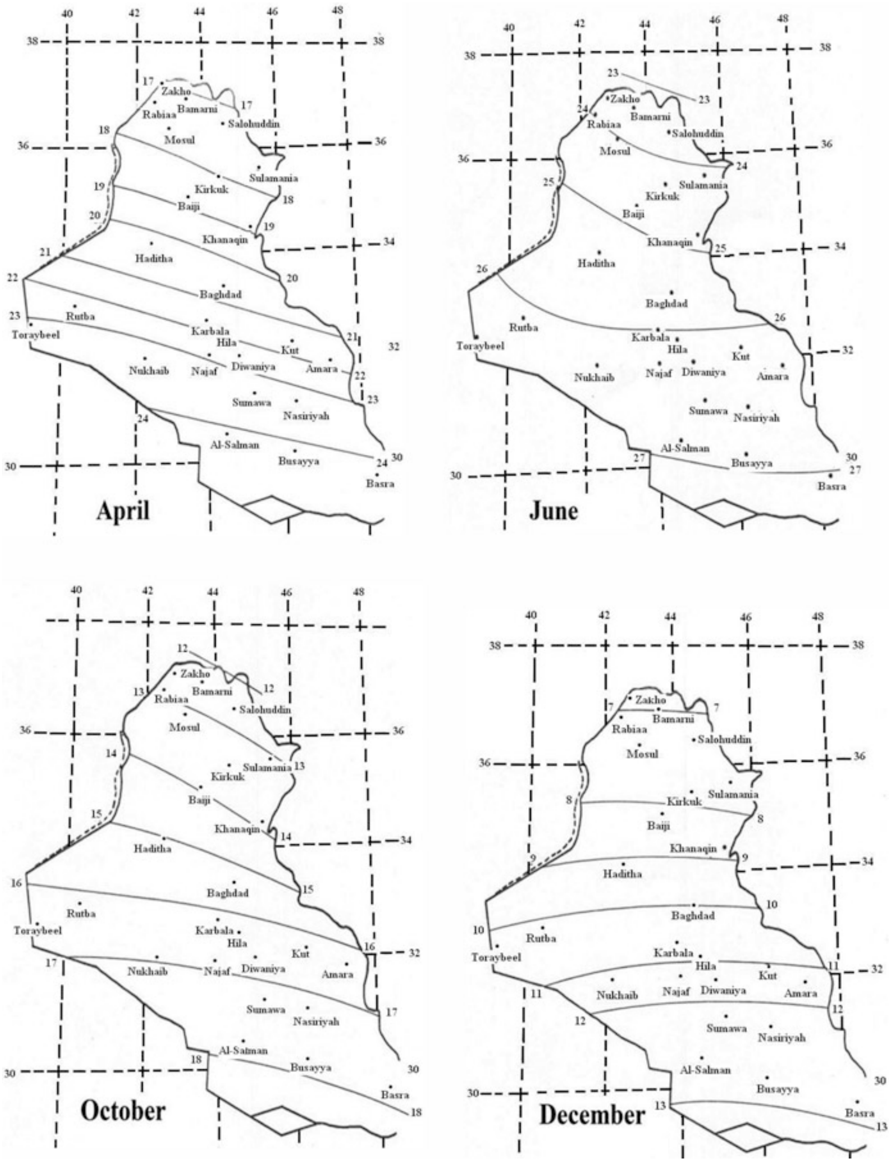

Fig. 3.3 Solar radiation lines for other months of Iraq [25]

3.3 Solar Energy in Iraq

Iraq is known for its bright sun for long hours, as the weather data showed that Iraq has about 3300 h of brightness radiation annually in Baghdad. The solar radiation intensity per hour ranges from 416 W/m^2 in January to 833 W/m^2 in June. Solar brightness hours in most countries of the world and even in Spain, which is one of the developed countries in the use of solar energy, cannot, in any way, compete with Iraq. Studies on the use of solar energy in Iraq began in 1973 after the energy crisis that occurred after the October 1973 war. Many studies have been completed to reach equations that can represent the density of solar energy in Baghdad and other cities [17]. At the time, most of the theoretical and practical studies in this area focused on the study of solar water heaters and refrigerators using solar energy. Studies and theoretical research began with the construction of theoretical models, such as the mathematical and numerical representation of solar water heaters. The Iraqi studies in this regard showed a good agreement between the practical and theoretical results [18, 19]. Subsequent studies have been looking at finding acceptable ways to improve the efficiency of solar applications in generating power and introducing variables and weather factors. Iraqi researchers studied the possibility of using high-concentration solar energy in the production of hydrogen for energy purposes, as this gas is considered an energy transporter and has a clean burning [20]. The researchers also studied theoretically and experimentally using the Trombe walls in the Iraqi winter environment [21, 22]. Several successful studies have been carried out using the industrial salt gradient pond and using it for energy stored in various applications such as heating greenhouses for agricultural purposes and increasing the productivity of solar distillates bound to the solar pond [23].

Solar radiation data is one of the most fundamental demands for the use of solar energy applications in an optimal economic way. Iraqi researchers have considered measuring and recording solar energy data in all Iraqi areas as one of the key issues for assessing the benefits of this energy in Iraq [24]. Many of these researchers used the latest mathematical relationships that link temperature, humidity, and solar radiation period. The results of these studies and measurements showed a good accuracy in the provision of solar radiation data for each area of Iraq. Relationships were found for three areas in Iraq. Figure 3.3 represents an annual and monthly solar radiation map for the radiation period from 24 stations in all Iraqi territory [25].

The Iraqi experiment in using photovoltaic cells (PV) began in an unsuccessful manner. Photovoltaic cells were used to illuminate street lights. The experiment failed due to the use of low-efficiency solar cells, and maintenance of these cells was nonexistent, causing the accumulation of dust on them (Iraq is characterized by the rise of dust for several days every month) [26]. These factors have caused popular unsupported for the use of photovoltaic cells throughout Iraq. Today, photovoltaic cells have shy uses and little power in processing electricity for individual residues, pumping water for agricultural purposes, and using it for telecommunication systems in areas that are difficult to access the power grid [27].

The basic specifications of solar radiation in Iraq can be summarized as follows:

- In the southern region, the annual change varies by about 200%, ranging from 13 MJ/m^2 in December and January to 27 MJ/m^2 in June and July. In the northern regions, the change is about 300% from 7 MJ/m^2 in December and January to 23 MJ/m^2 in June. In the central regions of Iraq, the annual change is about 250% and represents the average annual change of the northern and southern regions.

- There is a strong decline in the intensity of solar radiation from north to south, as it increases in winter and decreases in the summer. There is a more consistent distribution of solar radiation throughout Iraqi territory in the summer (June to August).
- The eastern-western descending is considered small and lies in the appraisal error.
- Data measured by meteorological stations in large cities and towns receive less radiation from areas away from cities due to pollution, so real radiation can be considered to be slightly more than the measured values included in the data [13].

3.3.1 Photovoltaic (PV) Systems

The uniform distribution of solar radiation throughout Iraq makes use of PV technology suitable for use throughout the country to produce electricity. Photovoltaic electricity generation technology is also suitable outside the grid in the case of power plants in rural desert areas. Which is effective in reducing the capacity of these cells are the high temperature of the air and the accumulation of dust and pollutants. The weather is soaked in Iraq and sometimes causes a lack of visibility due to dust storms.

3.3.2 Solar Concentrated Power Stations (CPS)

The concentration of solar energy in Iraq can be considered very suitable for the operation of power plants with the concentration of solar radiation. The establishment of such stations to improve the use of the electric power supply due to the high temperature was studied in detail. Studies have shown that the use of solar water heater systems by individuals has begun to increase locally.

Before undertaking a major project, it is necessary to study thoroughly the factors affecting the applications of photovoltaic systems and/or CPS systems. The efficiency and reliability of these systems depend on several factors such as orientation (latitude and longitude), weather and environmental conditions (solar intensity, temperature, humidity, wind, dust, rain, pollution, etc.), and the technology used.

3.4 Wind Energy in Iraq

Several studies and research works have been carried out to assess wind energy in different regions of Iraq. Twenty-three stations were set up and operated for measurements and analysis. The measurements showed that the daily model of wind speed is at its maximum value in the middle of the day and also in the early morning hours. Maximum wind speed values ranged between 5 m/s and 10 m/s. The measurements also showed that wind speed in summer is higher than its winter records. The increase in the demand for electricity in summer can be considered a positive issue when considering the establishment of wind farms as the load of cooling and electrical ventilation increases in summer compared to the demand in the winter [27].

Iraq can be divided into three areas of wind: In the first area, accounting for 48% of the area of Iraq, the wind speed is between 2 m/s and 3 m/s. The second region represents 35% of the area of Iraq, and the wind varies in this region between 3.1 m/s and 4.9 m/s. The third region represents 8% of the area of Iraq with relatively high wind speed more than 5 m/s. Field measurements and cities stations measurements showed that the energy density in the wind regions is: in Al-Emarra about 174 W/m^2, Al-Nekhaib about 194 W/m^2, Al-Kout about 337 W/m^2, Aana about 353 W/m^2, and Al-Naseria about 378 W/m^2. The average energy about 287.2 W/m^2 can be obtained [13].

3.5 Biomass Energy in Iraq

Biomass refers to solid biomass (consisting of organic matter and inorganic matter), biogas (mainly methane and carbon dioxide, resulting from bacteria forming anaerobic digestion of solid biomass; this biogas is used burned for heat and energy production), and liquid waste (a liquid fuel produced by a mass of biomass and now used in transportation); municipal waste is the waste that is expended by houses, shops, and public offices and is burned in heat and energy plants [28, 29].

Sugarcane and maize can be considered the most successful biomass types that can be used to produce biodiesel. Also, there are dates and other types of cane (growing in the marshes) that can be used in the production of bioethanol. These plants mentioned above are grown abundantly in Iraq and in large quantities. One of the obstacles to the quantitative and commercial production of Iraqi biofuels is the suffering of the agricultural sector in this country from neglect for decades, and to date the agricultural system are working with old technology, and the lack of agricultural credit and the deterioration of the overall situation of irrigation systems and infrastructure. All of these obstacles have caused biomass energy to be neglected despite its economic benefits [30, 31].

Despite the richness of Iraq in biomasses, unfortunately, this important source remains much neglected by the successive Iraqi governments. The abundance of oil and natural gas production, with easy access to financial returns, are the main reasons for neglecting the focus on taking advantage from biomass. However, this neglect did not prevent Iraqi researchers from studying the economic benefits, methods of manufacturing, and the environmental benefits from all types and forms of biomass. The Iraqi researcher studied the use of bioethanol and methanol in the operation of compression ignition and spark-ignition engines. These studies have concluded the promising potential and benefits of adding ethanol and methanol to all diesel and gasoline to improve combustion quality and reduce emissions. The use of ethanol or bio-methanol can reduce the high sulfur content of Iraqi diesel (about 10,000 ppm) and improve the octane number of gasoline [31, 32].

3.6 The Electricity Conditions in Iraq Today

Iraq was exposed during the period from July 14, 1958 onward to several successive coups followed by several successive wars since 1980. All these alarming situations and rapid changes have affected the electricity sector as is the case with other sectors. Iraq's electricity infrastructure was badly damaged during the Gulf War of 1991 and suffered from lack of funding and investment and the lack of equipment and spare parts for power plants under sanctions and an unjust blockade. The electricity sector suffered once again after the US invasion in 2003 and the ensuing occupation of the country. Also, the acts of war and the fighting of terrorist groups have caused a serious damage to the electricity system, whether generating or transmission lines or transformers. Iraq needs more investment in the electricity sector due to increased population growth [30]. The need to increase electricity production and provide it for the largest possible space is not only to cover the daily shortage of processing but also to support economic development. According to Ministry of Electricity advertisement, peak demand for electricity in 2008 amounted to 12,000 MW of electricity, while the Ministry of Electricity and all operating stations could only provide more than 6000 MW. If this gap between production and demand continues, the deficit is likely to grow to around 25,000 MW by 2020. It is worth mentioning that Iraq's renewable energies have not yet contributed to the energy generated by any proportion other than the production of electricity from dams [32].

The Ministry of Electricity contracted with many companies to build new power plants. The main image of these contracts is the reliance on oil and natural gas as fuel for these plants. Table 3.1 represents the new contracted stations and the fuel used with its source. In recent days after the invention of large ambushes for NG and directions to be used as fuel for power generation, many new plants have been contracted to work with diesel and NG. Table 3.2 represents stations and location of

Table 3.1 New stations and its capacities with the used fuel

Location	Capacity MW	Fuel
Shat Al-Arab	125 × 6	Fuel oil/Al-Basra refinery
Al-Khairat	125 × 6	Fuel oil/Al-Basra refinery
Al-Anbar	125 × 4	Fuel oil/Carbala refinery
Al-Naseriya	125 × 4	Fuel oil/Al-Naseriya refinery
Al-Doura/location 3	125 × 6	Fuel oil/Al-Doura refinery
Al-Doura/location 2	125 × 4	Fuel oil/Al-Doura refinery
Nineveh	125 × 6	Fuel oil/Al-Kasak refinery
Al-Dewaneia	125 × 4	Two units of gas and two unit of fuel oil
AL-Qudus	125 × 2	Fuel oil/gas at future
Al-Amara	125 × 2	Fuel oil/Al-Amara refinery
Wasit	125 × 2	
Al-Samawa	125 × 4	Fuel oil/Al-Samawa refinery
Al-Mansouriya	125 × 2	Gas from Al-Mansouriya field
Al-Najaf	125 × 4	Two units of gas and two units of fuel oil

Table 3.2 New power generation stations using NG

No.	Project	Location	Fuel used	Capacity
1	Al-Garaf station	Thee Qar	Fuel oil/NG	125 MW
2	Al-Garaf steam station	Thee Qar	Natural gas	300 MW
3	Al-Khairat steam station	Karbala	Fuel oil/NG	300 MW
4	The North steam station	Al-Mosel	Fuel oil/NG	300 MW
5	The North steam station	Al-Anbar	Crude oil/fuel oil/NG	300 MW
6	Shat Al-Arab Basra steam station	Al-Basra	Fuel oil/NG	300 MW

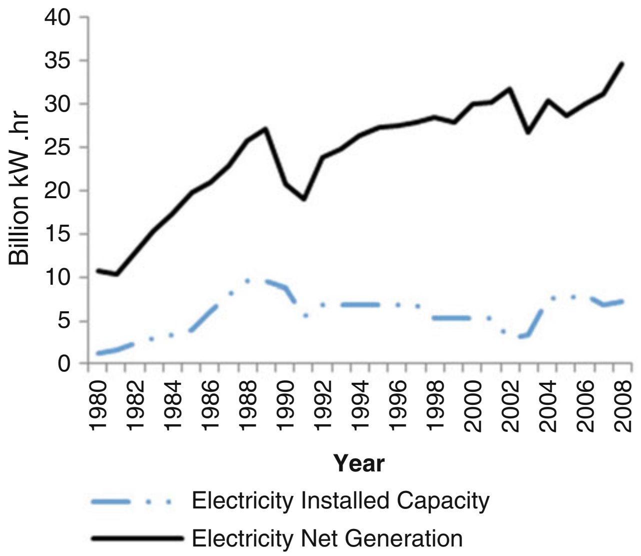

Fig. 3.4 Projection of the peak demand in Iraq till 2008

these new power plants, which operate on two fuels (liquid diesel and NG) [31]. The new power plants seem to be consuming fossil fuels, and they still have the same environmental hazards to health and air quality.

The demand/supply gap in Iraq is more than 183.33% on average, while the gap in developed countries is less than 150%. As the economy of Iraq is one of the growing economies, especially with the increase in oil prices and the start of this country to export natural gas starting from 2017, it is expected to increase the average per capita consumption of electricity. The Iraqi electricity sector needs large investments to meet the growing demand for electricity. International statistics estimate the amount spent on the electric power sector at US $ 80 billion for the period 2003–2017. Despite the huge value of the numbers, the crop was reduced due to administrative corruption in the body of the Iraqi state and the wrong practices of many citizens and their blatant disregard for the system. In addition to what the terrorists have done to destroy the infrastructure of stations and transmission and distribution lines in the areas they controlled for the period from 2014 until 2017.

The generation of electric power produced from conventional thermal power plants and hydroelectric power plants increased from 12.86 billion kilowatt hours in 1980 to 34.6 billion kilowatt hours in 2008. For the same period, electricity consumption (net generation, electricity import, electricity exports, and electricity losses) increased from 10.167 to 33.5 billion kWh. The installed electric power increased from 1.3 in 1980 to 7.2 GW in 2008, as shown in Fig. 3.4.

References

1. Kazem HA (2011) Renewable Energy in Oman: Status and Future Prospects. Renew Sust Energ Rev 15:3465–3469
2. Dehghan AA (2011) Status and potentials of renewable energies in Yazd Province-Iran. Renew Sust Energ Rev 15:1491–1496
3. Anagreh Y, Bataineh A, Al-Odat M (2010) Assessment of renewable energy potential, at Aqaba in Jordan. Renew Sust Energ Rev 14:1347–1351
4. Chaichan MT, Kazem HA (2011) Thermal storage comparison for variable basement kinds of a solar chimney prototype in Baghdad - Iraq weathers. Int J Appl Sci (IJAS) 2(2):12–20
5. CIA World Factbook (2011) Iraq country study. Central Intelligence Agency. http://www.cia.gov/cia/publications/factbook/geos/iz.html. Accessed 17 Dec 2011
6. http://www.unicef.org/media/publications/iraqsitan2002nationalcon.txt
7. http://geography.about.com/gi/dynamic/offsite.htm?site=http://lcweb2.loc.gov/frd/cs/ iqtoc.html
8. Aitken DW, Schirtzinger W, Strong S (2000) SMUD PV Program Review. i-143, www.donaldaitkenassociates.com/smudpvprogram. Accessed 17 April 2005
9. http://www.globalsecurity.org/military/world/iraq/images/iraq_usmc-book_topo-map.jpg
10. http://www.arab.de/arabinfo/iraq.htm
11. http://www.fao.org/ag/agl/aglw/aquastat/countries/iraq/index.stm
12. United Nation Environment Programme, United Nation in Iraq (2007) Post-conflict assessment, clean-up and reconstruction, Job No.: DEP/1035/GE, ISBN: 978-92-807-2906-1
13. Ahmed ST (2010) A review of solar energy and alternative energies applications in Iraq, the first conference between Iraqi and Germany Universities DAAD, Arbil
14. General Electric, Iraq Exploration Team Trip Report, briefing slides (2003)
15. Government of Iraq Ministry of Electricity (2010) Government of Iraq budget figures, cited in Centre for Strategic and International Studies, Iraq after the election: meeting the challenges of 2010, Presentation July 2010
16. Borja R, Phillips J, Austin C (2005) Operation solar eagle: a study examining photovoltaic (PV) solar power as an alternative for the rebuilding of the Iraqi electrical power generation infrastructure, Master of Business Administration, NAVAL Postgraduate School
17. Hadi JM (2005) Experimental & theoretical study to enhance solar air heater by using vortex generator, M.Sc. Thesis, University of technology, Iraq
18. Al-Rawi AM (2007) An experimental and theoretical study to improve the performance of a solar water heater of pyramidical right triangular cross-sectional area, M.Sc. Thesis, University of technology, Iraq
19. Alawi WH (2007) Numerical and experimental study of the solar collector /storage pyramidical right triangular cross sectional area, M.Sc. Thesis, University of technology, Iraq

20. Mohamad-Rassol HF (2008) Theoretical and experimental study of using solar energy to produce hydrogen gas, M.Sc. Thesis, University of technology, Iraq
21. Abass Kh I (2009) Experimental study to improve thermal performance of simple solar energy collecting wall. Wassit J Sci Med 2(2):212–221
22. Abass Kh I, Chaichan MT (2009) Experimental study of using solar energy storage wall for heating Iraqi houses purposes. Wassit J Sci Med 2(2):212–221
23. Chaichan MT, Abaas Kh I, Hatem FF (2009) Experimental study of water heating salt gradient solar pond performance in Iraq, Industrial Applications of Energy Systems (IAES09), Sohar University, Oman
24. Ahmed I, Al-Hamadam N, Ibrahim K (1983) Solar radiation maps For Iraq, SE 31(1-D), 29–44
25. Ahmed ST (1988) Study of Single-Effect Solar Still with an Internal Condenser. Solar Wind Technol 5(6):637–643
26. Austin C, Borja R, Phillips J (2005) Operation solar eagle: a study examining photovoltaic (PV) solar power as an alternative for the rebuilding of the Iraqi electrical power generation infrastructure, MBA Professional Report, Naval Postgraduate School Monterey, California
27. Khalifa AN (2011) Evaluation of different hybrid power scenarios to Reverse Osmosis (RO) desalination units in isolated areas in Iraq, Energy for Sustainable Development, pp 1–6
28. Meisen P, Avinash HN, Timbadiya P (2010) Overview of sustainable renewable energy potential of India, Report for Global Energy Network Institute
29. Al-Karaghouli A (2009) Current status of renewable energies in the Middle East – North African Region, Study by UNEP/ROWA
30. United State Department of Agriculture (2009) Fact sheet for USDA at work for agriculture in Iraq. Available at: https://photos.state.gov/libraries/iraq/216651/USDA/finalfasfactsheet11172009.pdf
31. Saleh AM, Chaichan MT (2010) The effect of alcohol addition on the performance and emission of single cylinder spark ignition engine, Proceeding to Najaf Technical collage international scientific conference, Najaf, Iraq
32. Chaichan MT (2010) Emissions and performance characteristics of ethanol-diesel blends in CI engines. Eng Technol J 28(21):6365–6383

Chapter 4
Solar Photovoltaic Technology Principles

4.1 Introduction

Throughout the years, nonrenewable sources of energy have been, and still remain, the world's number one source of energy. According to a BP review [1, 2], fossil fuels satisfy about 86% of the world's energy consumption as of 2014, with nuclear energy contributing 4.4%, leaving the shares of hydropower and other renewables at about 6.8% and 2.5%, respectively, i.e., less than 10% of the total world's energy requirements are satisfied by renewable sources. Figure 4.1 compares between the renewable and non-renewable energies [3, 4].

Nonrenewable energy sources, no matter how "plentiful," are finite and, when compared to their renewable counterparts, are fairly limited. The fact that so little of the world's energy demands (i.e., less than 10%) are satisfied with the most abundant resources on Earth is alarming, not only due to the resulting waste of energy potential but the loss of the cost-effectiveness of utilizing such resources (lack of fuel costs, longer system life cycle resulting in lower maintenance costs, technological advancements from research into such areas raising national and global scientific levels, overall cost and resource savings that could be rerouted to further goals in academic, social, and other fields, etc.). Additionally, emissions (greenhouse gases like CO_2, other air pollutants such as nitrogen and sulfur oxides, etc.) and waste (radioactive waste from nuclear energy, waste produced by factories and coal−/oil-burning power plants, etc.) produced by such resources harm the environment as well as every living thing within it, especially with the large amount of waste disposal issues present worldwide and the further implications caused by these issues (global warming, ozone layer depletion, smog production, etc.). But, with the advent of renewable and "clean" energy, such threats can be minimized and eventually eliminated through set initiatives that incentivize moving to clean energy in addition to raising awareness of the benefits of switching to these resources [5–10].

In order to exploit the potential of solar energy, however, one of two technologies must be utilized: concentrated solar power (CSP) or photovoltaics (PVs). In simple

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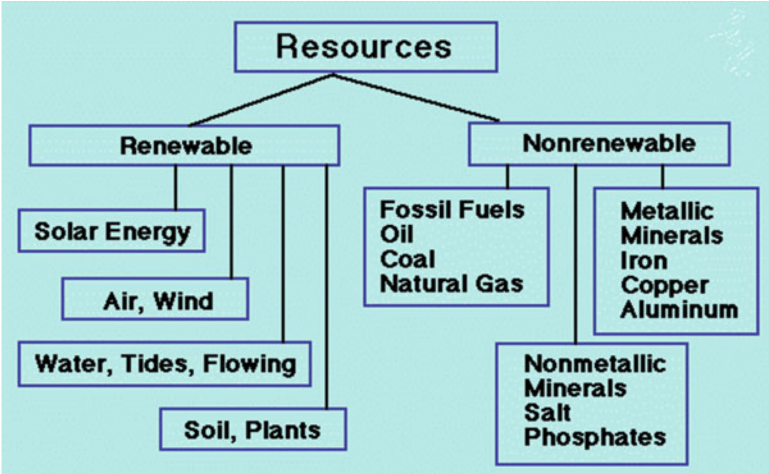


Fig. 4.1 Comparing renewable and nonrenewable energy sources [3, 4]

terms, CSP systems convert solar energy into solar thermal energy concentrated onto a small area to produce heat, which is then converted to electricity via an engine or turbine, whereas PV systems convert solar energy into DC electricity through semiconductor cells.

What the previously mentioned statistics don't show is the continuously increasing growth in the utilization of solar energy in both forms, both on the global and local scales, only it is not as significant on a global scale as it is in certain individual countries as of yet [11–13]. For example, in 2004, the solar PV and CSP global capacities were at 3.7 GW and less than 0.5 GW, respectively, as opposed to 177 GW and 4.4 GW, respectively, in 2014, thanks to technological advancements, the resulting cost reductions, and the general shift in tone from both companies and nations when it comes to renewable energy in general, and solar energy in particular [5]. Additionally, major projects have also made their mark, such as the Topaz Solar and Desert Sunlight PV power plants (each having 550 MW capacities and in the United States) or the Ivanpah CSP plant (377 MW and in the United States) on the global scene.

Principles of photovoltaic taught at universities are presented in this chapter. In addition, a discussion of the effects of solar radiation and different elements on photovoltaic systems is provided to understand the principles, design, operation, and performance of these systems. This chapter begins with a discussion about solar radiation, insolation, elements that affect solar radiation, and insolation on tracking surface, stationary surface, and horizontal surface.

The later part of this chapter discusses photovoltaic (henceforth PV) history, structure, types, performance parameters, operation, and design. In addition, a discussion on the elements that affect PV is present. By the end of this chapter, a clearer image on PV operation and performance to the reader will be established.

The following subtopics will be explored: solar energy radiated from the sun, the radiation observed by the atmosphere and collector (PV), PV electrical production, and finally the power received by the electrical load.

4.2 Insolation and Solar Radiation

It is safe to define solar radiation as a beam produced/emitted by the sun. The maximum amount of this radiation, also known as "flux density," to reach the surface of the Earth is about 1 kW/m^2 in a wavelength band from 0.3 μm to 2.5 μm. This is referred to as a shortwave radiation which contains the visible spectrum. Whereas, the radiation energy fluxes that are emitted by the Earth occur in an infrared wavelength band from 5 μm to 25 μm, with same order of radiation of 1 kW/m^2 and is referred to as longwave radiation. The solar radiation is divided into two categories; "extraterrestrial solar radiation" and "global solar radiation" [1, 2]. The term "extraterrestrial" is used for solar radiation outside the atmosphere or in space. The extraterrestrial solar radiation, G_{extra}, is given by

$$G_{\text{extra}} = I_{\text{o}}\left[1 + 0.034\cos\left(\frac{2\pi d}{365}\right)\right] \tag{4.1}$$

where I_{o} is the solar constant, 1367 W/m^2, and d is the number of days.

Solar radiation in space has a much higher energy density than those that reach Earth, and the reason is the ability of the Earth's atmosphere to absorb a fraction of solar radiation. This absorption is occurring in upper atmosphere which only absorbs radiation with frequencies above 1000 THz (300 nm) initiating photo-ionization, which leads to photochemical reactions and ultimately heating up the air. The ozone layer, near 25 km altitude, absorbs most of these radiations and is, the layer, astonishingly opaque to ultraviolet. Even though various mechanisms cause the generation of solar radiation, the main reason considered is the black body type. Planck's law represents the energy per unit volume per unit frequency interval inside a hollow isothermal black body as shown in Eq. (4.2):

$$\frac{dW}{df} = \frac{8\pi h}{c^3}\frac{f^3}{\exp(hf/kT) - 1} \qquad \text{J.m}^{-3}.\text{Hz}^{-1} \tag{4.2}$$

Energy flus (same as power, P) is:

$$\frac{dP}{df} \propto \frac{f^3}{\exp(hf/kT) - 1} \qquad \text{WJ.m}^{-2}.\text{Hz}^{-1} \tag{4.3}$$

In terms of wavelength, $\frac{dP}{d\lambda} \propto \frac{\lambda^{-5}}{\exp(hf/kT\lambda)-1}$ WJ.m^{-2} *per m of wavelength interval,* global solar radiation is generally described as the "total solar radiation that reaches the Earth's surface." The global solar radiation on a tilt surface is composed of three

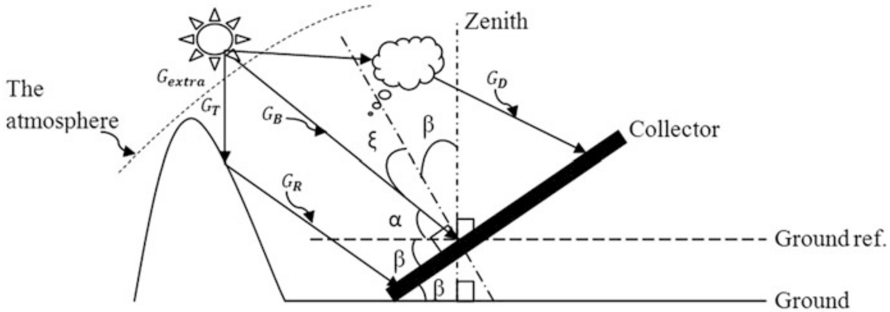


Fig. 4.2 Radiation components of solar energy on a collector with tilted surface

components [3, 4], which are "direct solar radiation" (G_B), "diffuse solar radiation" (G_D), and "reflected solar radiation" (G_R), as shown in Fig. 4.2.

From Fig. 4.1, the global radiation which falls on a tilt surface is given by,

$$G_T = G_B + G_D + G_R \tag{4.4}$$

However, on a horizontal surface $G_R = 0$ and therefore, the amount of global solar radiation is given by

$$G_T = G_B + G_D \tag{4.5}$$

The amount of global solar radiation is contingent on the "sky clearness index," K_T, which is given by

$$\frac{G_T}{G_{extra}} = K_T \tag{4.6}$$

where the value of K_T ranges between 0 and 1. Here, if the sky is overcast, then little amount of solar radiation is received and vice versa [2].

The amount of solar radiation to be scattered by clouds and impurities in the sky is named diffuse solar radiation. The "diffuse solar radiation index" K_D is given by,

$$\frac{G_D}{G_T} = K_D \tag{4.7}$$

The reflected solar radiation is estimated by using

$$G_R = G_T \rho \tag{4.8}$$

where ρ is the "ground albedo" and it is usually of values 0.1, 0.2, and 0.3 for soil, sand, and grass, respectively.

Solar energy is the "amount of solar radiation multiplied by time." Therefore, the daily global solar energy on a horizontal surface is the "average of the daily global solar radiation multiplied by the length of the solar day" which is the time from sunrise to sunset. The "solar day length" (S_o) is calculated by using

$$S_o = \frac{2}{15}\cos^{-1}(-\tan L.\tan \mathrm{DEC}) \tag{4.9}$$

where L is the "latitude" and DEC is the "declination angle." Based on the solar day length, the "extraterrestrial solar energy" (E_{extra}), "global solar energy" (E_T), "beam solar energy" (E_B), and "direct solar energy" (E_D) can be determined by multiplying G_{extra}, G_T, G_B, and G_D with S_o, respectively.

4.3 Insolation

4.3.1 Geometry of the Sun

Insolation is defined as the "power density of the solar radiation." Whereas, solar constant has been defined, in Sect. 4.2, as the "insolation on a surface that faces the sun outside earth's atmosphere." The solar constant's value is approximately 1360 W\m^2. In addition, it is suitable to describe surface solar constant as "the value of insolation on a surface that, at sea level, faces the vertical sun on a clear day." The value of this "constant" is around 1000 W\m^2 or "one sun." The insolation is smaller at non-vertical situation of the sun and because of the larger air mass that solar rays must pass through.

The insolation depends on [1]:

1. The level of transparency of the atmosphere
2. Relative orientation of the surface with respect to the sun

The main sources of errors are:

1. The assumption that throughout the year, the period between successive sunrises remains constant, which is inaccurate, so the "equation of time" is implemented for correction, which will be discussed in Sect. 4.3.2.
2. The implementation of "mean local time" which is different from civil time (the time measured at the center of each time zone) in different formulas.

   Error sources 1 and 2 could be easily rectified through introduction of the concept of "time offset" (see Sect. 4.3.2).

3. Considering the geometry of the situation and using it in the formulas reduce the accuracy. This is an error due to diffraction of the light, which occurs as resultant of presence of the atmosphere, where the sun's visibility remains when it is fairly below the geometric horizon. This leads to the geometric sunrise to be after the apparent one and the apparent sunset to be later. To rectify this error, a solar zenith angle at sunrise and sunset of 90.833 should be implemented instead of the geometric 90.

4. The assumption of a perfectly transparent atmosphere during collection of the insolation data. This is inaccurate as meteorological conditions majorly alter the amount of useful sunlight.

Latitude (*L*) represents the south to north location of a point on the Earth, while longitude (*LOD*) represents the west to east location of a point on the Earth through the measurement of angular distance from the Greenwich meridian (or Prime meridian, where longitude is 0) along the equator.

However, many angles can describe the position of the sun in the sky, such as "hour angle" (*HA*), "angle of declination" (*DEC*), "solar altitude" (*SOLAL*), "solar azimuth" (*SOLAZM*), "solar zenith angle" (*SOLZN*), and "solar incidence angle" (*SOLIN*). The definition of zenith angle is "the angle between the local vertical and the line from the observer to the sun," and the azimuth angle is "the azimuth from north of the sun's beam projection on the horizontal plane clockwise positive." This is a topocentric system, where the observer is at the origin of the coordinates. Two different points of view have been implemented: a "geocentric system" (origin at the center of Earth) and a "heliocentric system" (origin at the center of the sun). Both *SOLZN* and *SOLAZM* are functions of the day of the year (*d*), the local time of day (*t*), and the latitude of the observer (*L*) in our top-centric system (Fig. 4.3).

Observe that the time, ***t***, in the formulas is not the same as the time in our watch. The difference in these times is described as the time offset which is formed of two components; one of them is the difference due to the equation of time (*EOT*) and the other owing to the longitude of the place of interest from that of the center of the time zone [5].

Time of the day represents the "hour angle" (*HA*), which was generally used by astronomers in the past, who mostly worked at night, and so counting a new day from noon rather than from midnight is the preferred method. They defined the hour angle as

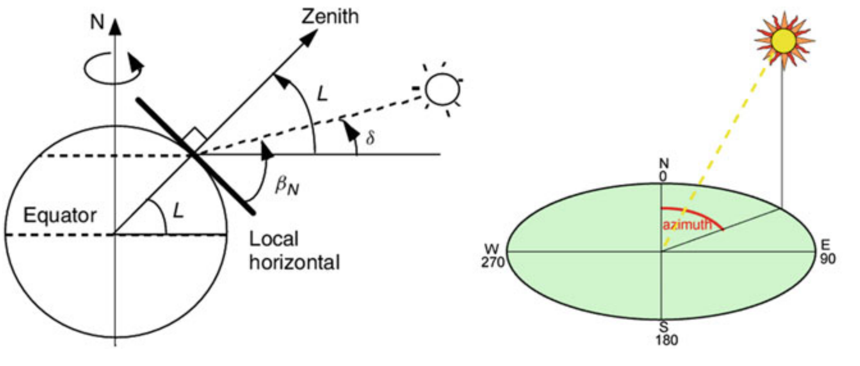


Fig. 4.3 Solar zenith angle

$$\mathrm{HA} \equiv \frac{360}{24}(t-12) \qquad \text{Degree } (t \text{ in h}, 24-\text{h clock}) \tag{4.10}$$

$$\mathrm{HA} \equiv \frac{2\pi}{86400}(t-43200) \quad \text{Radians } (t \text{ in h}, 24-\text{h clock}) \tag{4.11}$$

The solar declination (*DEC*), by the latitude of the sun, represents the day of the year or "season."

$$\mathrm{DEC} = 23.44 \sin\left[360\left(\frac{d-80}{365.25}\right)\right] \quad \text{degrees,} \tag{4.12}$$

The solar zenith and azimuth angles are calculated using [6]

$$\cos SOLZN = \sin \mathrm{DEC}.\sin L + \cos \mathrm{DEC}.\cos L.\cos \mathrm{HA} \tag{4.13}$$

$$\tan SOLAZM = \frac{\sin \mathrm{HA}}{\sin L.\cos \mathrm{HA} - \cos L.\tan \mathrm{DEC}} \tag{4.14}$$

where L is the latitude of the observer.

To determine *SOLAZM*, we must take $\tan^{-1}$ (tan *SOLAZM*). It is important to notice that $\tan^{-1}$ (tan *SOLAZM*) is not necessarily equal to *SOLAZM*. For instance, consider the angle 240° whose tangent is 1.732. The inverse tangent ($\tan^{-1}$) of 1.732 when calculated via calculator or a computer is 60° which is due to such devices that yield the principal value of $\tan^{-1}$ *SOLAZM* which, by definition, lies in the range from −90° to 90°. Therefore, the alternative formula to determining the solar azimuth is

$$\cos(180 - SOLAZM) = -\frac{\sin L.\cos SOLZN - \sin \mathrm{DEC}}{\cos L.\sin SOLZN} \tag{4.15}$$

At both sunrise and sunset, $SOLZN = 90°$; thus, cos ($SOLZN$) = 0. From Eq. 4.13,

$$\cos \mathrm{HA_R} = \cos \mathrm{HA_S} = -\tan \mathrm{DEC}.\tan L \tag{4.16}$$

where $\mathrm{HA_{R,S}}$ is the hour angle at either sunrise or sunset. The "hour angle" ($\mathrm{HA_R}$) at sunrise, is negative, while the $\mathrm{HA_S}$, at sunset, is positive.

$$\mathrm{HA_R} = -\mathrm{HA_S} \tag{4.17}$$

4.3.2 Time Offset and Zones

The "local mean solar time" depends on the observer longitude which varies by 1 h for every 15° of longitude which makes it an impractical measure of time. This use of time zones, 1 h or 15° wide, circumvents this difficulty. Since the time is the same regardless of the location of the observer in each region, the time suddenly changes by 1 h at the boundary of the area. Hence, for any time zone, the center meridian is a multiple of 15°; the first zone is squarely centered on the zeroth meridian that of Greenwich, where the time there is referred to as “Greenwich Mean Time” (*GMT*) (or, to astronomers, “universal time” (*UT*)).

The term “standard time” represents the zone time (such as, for instance, PST, for Pacific Standard Time, the −8 time zone centered at 120° W) [7].

The “true solar time” (t_{true}) at any given longitude (*LOD*) can be calculated using

$$t_{\mathrm{true}} = t_{\mathrm{localmean}} + t_{\mathrm{offset}} \tag{4.18}$$

where t_{local} and t_{true} are expressed in hours and minutes, but t_{offset} is in minutes only,

$$t_{\mathrm{offset}} = \mathrm{EOT} - 4\mathrm{LOD} + 60t_{\mathrm{zone}} \quad \mathrm{min}; \tag{4.19}$$

where *LOD* is the longitude in degrees (east >0, west<0), t_{zone} is the number of hours of the local time zone referred to the *UT* (east >0, west <0), and *EOT* is the equation of time (in minutes). The equation of time is the difference between the mean time and the apparent solar time and can be expressed mathematically as:

$$\begin{aligned}&\mathrm{EOT}\\&= 2.292(0.0075 + 0.1868\cos\mathrm{DD} - 3.2077\sin\mathrm{DD} - 1.4615\cos 2\mathrm{DD} - 4.089\sin 2\mathrm{DD})\end{aligned} \tag{4.20}$$

where the angle DD = $2\pi(d - 1)/365$ is in radians (Fig. 4.4).

4.3.3 Insolation on a Sun-Tracking Surface

Daily average insolation is

$$< p >= \frac{1}{T}\int_{t_{\mathrm{R}}}^{t_{\mathrm{S}}} P_{\mathrm{S}}.dt \quad \mathrm{W.m^{-2}} \tag{4.21}$$

If we assume, unrealistically, that the solar power density (P_{S}) is constant from sunrise to sunset, the average insolation (<*p*>), in terms of the hour angle, is

$$< p >= \frac{1}{\pi}\mathrm{HA_S}.P_{\mathrm{S}} \quad \mathrm{W.m^{-2}} \tag{4.22}$$

At the equinoxes, DEC = 0, and, therefore, $\mathrm{HA_S} = \pi/2$, and

$$< p >= \frac{1}{2}P_{\mathrm{S}} \approx 500 \quad \mathrm{W.m^{-2}} \approx 43.2\mathrm{MJ.m^{-2}.day^{-1}} \tag{4.23}$$

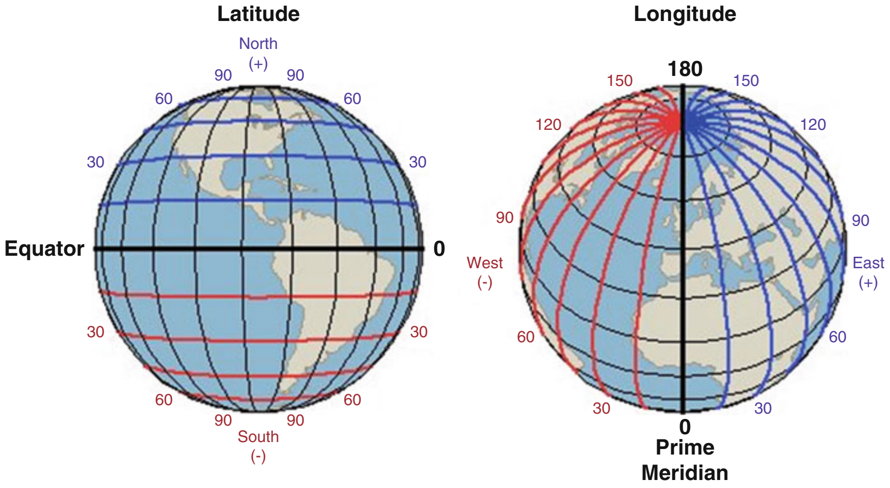
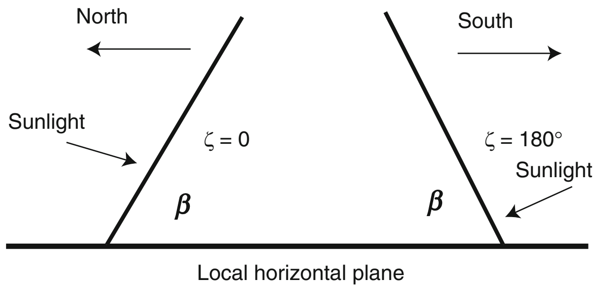


Fig. 4.4 Longitude and latitude

Fig. 4.5 Two solar collectors with different azimuths but with the same elevation



4.3.4 Insolation on a Stationary Surface

A surface with tilt or elevation, β, azimuth, ζ, has an instantaneous insolation (P), which is

$$P = P_S[\cos\beta.\cos SOLZN + \sin\beta.\sin SOLZN.\cos(SOLAZM - \zeta)] \tag{4.24}$$

As shown in Fig. 4.5, the elevation angle is always taken as positive. It is noteworthy to mention that it is important to assay the sun shining whether on the front or back surface. If it is shining on the front, then the yields have in a negative sign in the second term inside the brackets.

$$P = \frac{1}{T}\int_{t_R}^{t_S} Pdt = \frac{1}{2\pi}\int_{HA_R}^{HA_S} PdHA \tag{4.25}$$

4.3.5 Insolation on Horizontal Surfaces

For horizontal surfaces $\beta = 0$, Eq. 4.24 is reduced to

$$P = P_{\mathrm{S}} \cos SOLZN \tag{4.26}$$

Consequently,

$$\begin{aligned} P &= \frac{1}{2\pi}\int_{\mathrm{HA_R}}^{\mathrm{HA_S}} P_{\mathrm{S}} \cos SOLZN \\ &= \frac{P_{\mathrm{S}}}{2\pi}[\sin \mathrm{DEC}.\sin L(\mathrm{HA_S} - \mathrm{HA_R}) + \cos \mathrm{DEC}.\cos L(\sin \mathrm{HA_S} - \sin \mathrm{HA_R})] = \frac{P_{\mathrm{S}}}{2\pi}\cos \mathrm{DEC}. \\ &\cos L(2\sin \mathrm{HA_S} + 2\mathrm{HA_S}\tan \mathrm{DEC}.\tan L) = \frac{P_{\mathrm{S}}}{\pi}\cos \mathrm{DEC}.\cos L(\sin \mathrm{HA_S} - \mathrm{HA_S}.\cos \mathrm{HA_S}) \end{aligned} \tag{4.27}$$

At the equinoxes, DEC $= 0$, $\mathrm{HA_S} = \pi/2$, therefore

$$< P >= \frac{P_{\mathrm{S}}}{\pi} \cos L \tag{4.28}$$

At the equator, regardless DEC, $\mathrm{HA_S} = \pi/2$, therefore

$$< P >= \frac{P_{\mathrm{S}}}{\pi} \cos \mathrm{DEC} \tag{4.29}$$

4.4 Solar Cell and Photovoltaic

PV is a semiconductor device that directly converts light energy into electricity and is commonly known as “solar cell.” A common micro-application is the solar cell-powered small calculator. PV systems of larger size, which are more complicated, provide higher electricity for cities and industrial applications. This device is one of the most promising means and an energy source that provides to our energy-intensive standard of living while not contributing to global warming and pollution.

4.5 Photovoltaic Technology: A Brief History

In a solar cell or PV cell, the semiconductor absorbs the energy of the photons, from sunlight, which are then through the movement of electrons is converted to voltage. The electricity produced is direct current (*DC*), due to the unidirectional flow of these electrons across the cell. This technology is in fact old, where in the late 1830s the photovoltaic effect was discovered, and in 1883 it was first produced by Charles Fritts [8]. Einstein won the Nobel Prize in 1921 after presenting an explanation of the related photoelectric effect [9]. In 1954, a big breakthrough occurred in solar energy field where the first crystalline silicon solar cell was developed. Four years later, the technology was implemented to power a space satellite. The good news was that the cell performed well in outer space; NASA did not expect it to remain operational for an additional number of years, and the satellite continued to send data to the Earth even when it was not needed. This event helped spread the popularization of solar cells. In the mid-1970s, there was a shift in interest and the search for more sustainable energy sources resulting from the OPEC's oil crisis. Hence, more attention and money are being diverted to reach cheaper innovation and better solar cells. As a result of the high-rush and massive budgets were devoted for R & D in photovoltaic field, the first amorphous silicon cell was developed by Carlson and Wronski [10, 11].

The amorphous silicon solar cells were fundamentally cheaper material than standard crystalline silicon which caused an excitement in the field. This material is also used for the thin film transistors that drive modern flat-panel displays. They have been produced on massive scale and cheaply over the years causing a significant reduction in the price of flat panels. The same situation is occurring for solar cell prices.

In the 1980s, the efficiency of solar cells was developed and enhanced. Many types of solar cells were introduced. In the 1990s, solar cells were produced on a large scale with efficiency above 10%. Materials such as Ga-As and other elements of groups III and V of the periodic table such as CdTe, $CuInSe_2$, and TiO_2 desensitized, and finally the two largest producers of crystalline, polycrystalline, and amorphous silicon solar cells were used in the formation of these cells. At present, the price of solar cells continues to decline, and the third generation of new solar cells is being vigorously explored [12–17].

The National Renewable Energy Laboratory (NREL) has awarded, in August 2008, a PV energy device that converts 40.8% from the light absorbed by the cell into electricity, the world's first standard solar energy efficiency. This can be considered the highest proven efficiency of any system to date [18, 19].

The power generation potential of PV systems is unlimited, and along with its environmentally friendly nature, it can be considered a long-term reliable source of energy for the ever-expanding industrialized world. PV technology is a suitable candidate to achieve renewable energy goals, by meeting the goal of reducing emissions of carbon dioxide (Fig. 4.6).

Recently, rapid increases of globally installed PV systems have occurred, with a growth rate of about 30% for 8 consecutive years. In 2003, the total installed capacity of PV system around the world reached 1242 MW, and data attained in 2007 showed an outstanding growth rate of 62% over that of the previous year, with 2826 MW. In 2007, the global photovoltaic industry generated revenues of US $ 17.2 billion, the bulk of which was Germany, which installed 1328 MW and 47% of the global market. Spain's PV market has grown above 48% to 640 MW. For the

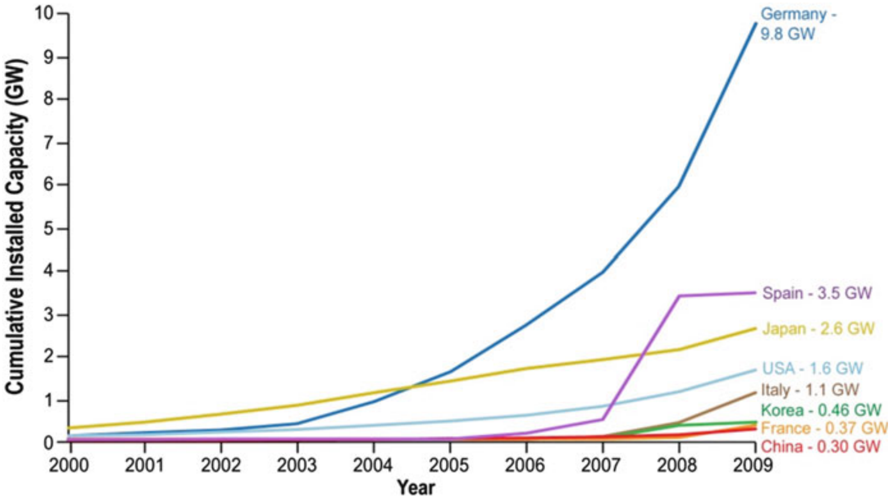


Fig. 4.6 PV cumulative installations [24]

United States, it has increased the share of photovoltaic power by 57% with more than 220 MW of installed power and represents about 8% of the global market. The United States became the No. 4 country in the world's main market after Japan. The above four countries collectively account for 86% of the world's PV market [20–23]. In 2009, Germany, Spain, Japan, and the United States installed an estimated 9.8, 3.5, 2.6, and 1.6 GW, respectively [24].

4.6 Photovoltaic Materials

Semiconductors form solar cells – most importantly silicon (Si) material. What makes semiconductor's electronic properties special is their tendency to conduct or insulate depending on their composition. Semiconductors (in yellow) are used for PV materials. The phosphorous and boron are the most impurities used in silicon solar cell doping. The main type of solar cell available today is the silicon-based technology. However, there are different types of solar cells such as cadmium telluride (CdTe) or copper indium diselenide or gallium arsenide (Fig. 4.7).

Silicon is an element from a group of four semiconductors, which its crystal is shaped as a diamond lattice. Figure 4.9 shows that each silicon atom uses four valence electrons placed in an identical position to each other, and every atom has four nearest neighbors. Silicon is used for manufacturing most solar cells. The bond in the Si is formed by four electrons to the nearest neighbors (as the red bonds in Fig. 4.8 represents). Silicon is a semiconductor responsible for the integrated circuit that made the modern computers possible [24].

Most of the current PV market uses silicon technology; Fig. 4.9 illustrates the difference between crystalline silicon and amorphous silicon. Crystalline silicon

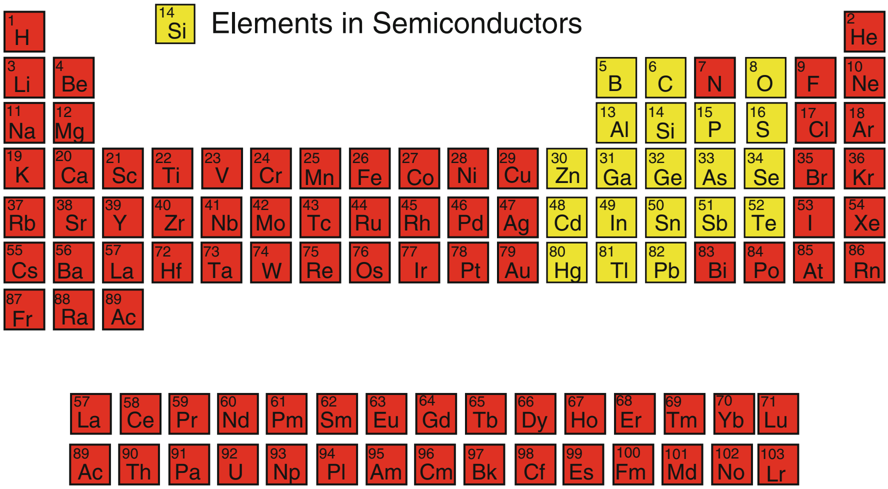


Fig. 4.7 Periodic table

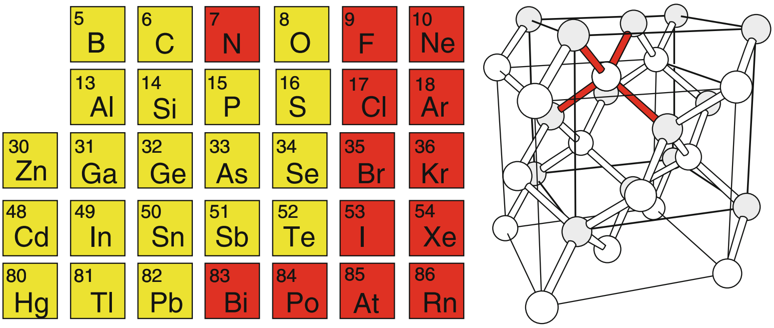


Fig. 4.8 Silicon crystal

technology represents an ideal hairstyle like a swan. As for crystallized silicon, there are tension and broken bonds and can be likened to an ugly duck. Physical deformations cause electronic defects and result in lower performance of solar cells.

4.6.1 Band Theory

There are three types of materials, according to band theory, which are differentiated by their electronic structure: “insulators,” “conductors,” and “semiconductors.” In fact, band theory models the behavior of electrons in solids by postulating the existence of energy bands, continuous ranges of energy which electrons may occupy, and gaps, which they may not. It successfully explains many physical

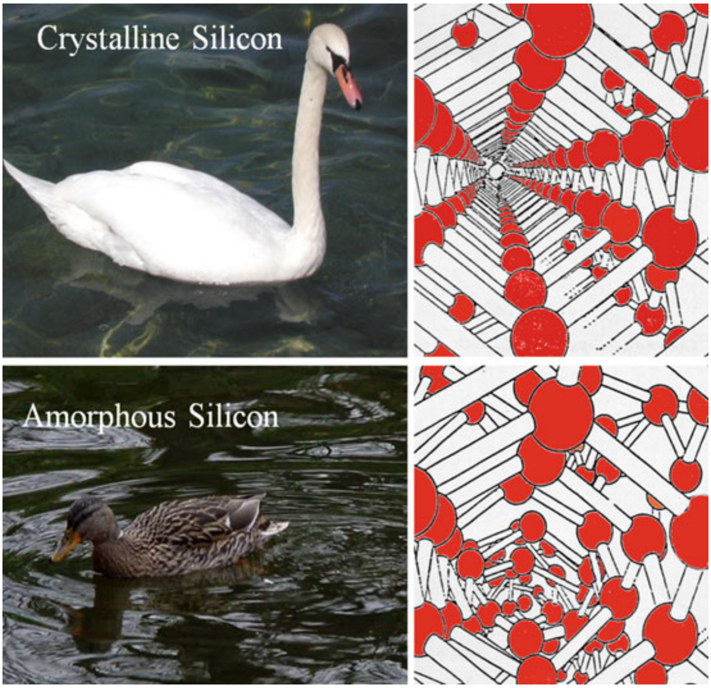


Fig. 4.9 Amorphous and crystalline silicon comparison [4]

properties of solids, such as optical absorption and electric resistivity. For the conductor, the "valence band" (E_v) is above conduction, creating free electrons ready to generate electricity. In the insulator, the two bands are far from each other, and the charge will be very hard to be gotten from the bottom (valence) to top band ("conduction band" E_c) [1]. There is what known as a "band gap" that represents a gap between the valence and conduction bands for the semiconductor, and sometimes it is denoted as "energy of the gap" (E_g). The "Fermi energy" (E_f) is also shown for the insulator and semiconductor. The ground state of a noninteracting fermions system (like one made up of electrons here) is constructed by starting with an empty system and adding particles one at a time, in a row filling up the lowest-energy unoccupied quantum states. The Fermi energy is the level (if there is one) where half of the states are occupied with electrons.

4.6.2 Semiconductor Energy Bands

The semiconductors are classified as shown in Fig. 4.10 into:

1. n-type
2. p-type
3. Intrinsic

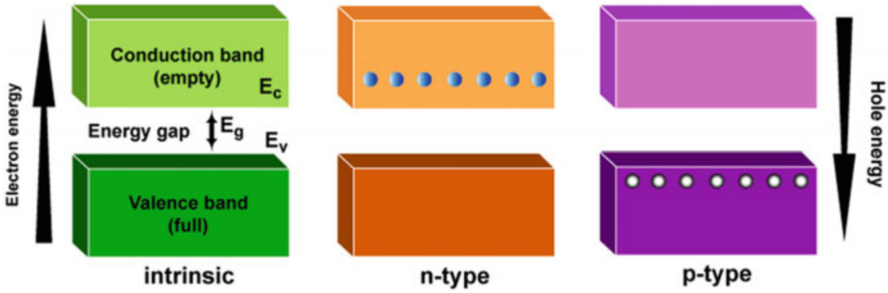


Fig. 4.10 p-types, n-type, and intrinsic semiconductor

The semiconductors that conduct electricity are types 2 and 3:

- By alloying semiconductor with an impurity also known as doping
- Carriers removed from valence band or carriers located in conduction band

4.6.3 *The Intrinsic-Type Semiconductor*

The intrinsic or pure semiconductor contains the right number of electrons to fill valence band. Consequently, the conduction band is empty. The pure semiconductor acts like an insulator because the electrons in full valence cannot move.

4.6.4 *The N-Type Semiconductor*

An atom from group 5 impurity is added to silicon melt from which crystal is grown so that the current is carried by the negatively charged electrons.

- The valence band filled by 4/5 of outer electrons.
- 1/5 left is then put into conduction band. These impurity atoms are called "donors."

The electrons move within conduction band; therefore, crystal becomes a "conductor."

4.6.5 *The P-Type Semiconductor*

Group 3 added to melted silicon and acts as positively charged particles by making the current carried by missing electron holes to:

- Doping creates lack of electrons in the valence band which needs four out of three outer electrons.
- Missing electrons, also known as holes, are used to carry current.

The existing charges are called the majority carriers. The existing charge carriers in n-type are "electrons." The existing charge carriers in p-type are "holes."

4.7 Creating a Junction

The semiconductor junctions can be classified into four main types:

- p-n
- p-i-n
- Schottky barrier
- Heterojunction

Each has a built-in potential. By putting two similar semiconductors together, we can create devices. The device is called a "junction" and there are four different types. Each type has a built-in potential (a built-in voltage) associated with them [6].

P-i-n and *p-n* junctions represent the first two types of intersections (the band gap and the coupling band) are shown in Fig. 4.11. Electrons cannot exist in the band gap, although semiconductors are not ideal. In the case of heat balance at room temperature, some cases appear in this band gap. The steel line represents the "Fermi level" and can be expressed by a fluid composed of electrons that are poured into the bucket (gap), and the filling point is the Fermi level. The Fermi level should remain

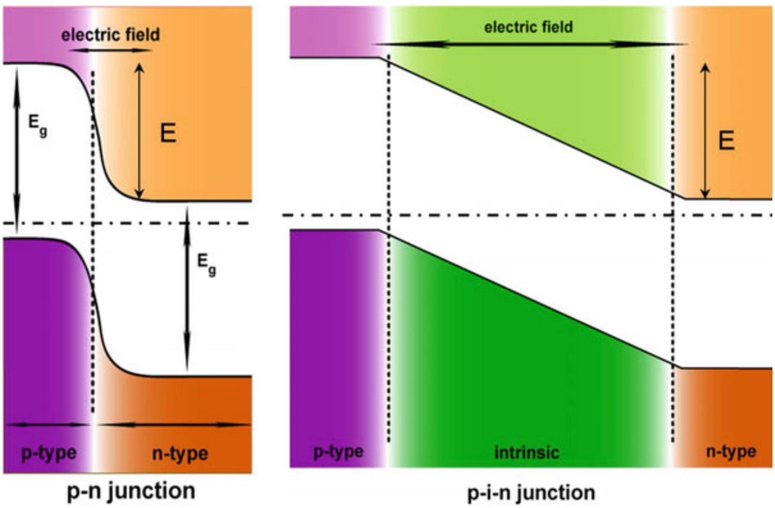


Fig. 4.11 "p-n" and "p-i-n" junctions

flat when dealing with semiconductors, especially when two different semiconductors are combined. This is what creates the bending of these bands (both the conduction and the valence teams).

So, in the p-n junction, there are the n and p layers. The Fermi level is extremely low in the p-type as the gap is pulled to the valence band. In semiconductor of the n-type, the Fermi level is very high and pulled toward the conduction band. As trying to keep Fermi level flat, there will be an enormous bending of the conduction and valence bands when they are combined. The bending creates the voltage and the electric field observed when putting two dissimilar (n and p) semiconductors together. The energy between the conduction band in the n and the p layers is the built-in potential.

As strong electric field is contained in the junctions, this field forms in the following steps:

- When two semiconductors contact to from n-type, the electrons near interface transfer over to p-type, compose a positive charged area.
- The p-type holes transfer to n-type forming a negatively charged area.
- Because holes and electrons exchange their positions, there will be formed a barrier of a middle potential where the charges will not transfer.
- No more holes or electrons will flow through these potentially created barriers.
- The electric field forces the holes and electrons to line up in opposite directions resulting in no net current and equilibrium to be occurred.
- At the p-side, when applying a positive voltage will lead to reduce the height of the barrier, it is called "forward bias" that will cause an increase of the PV current.
- In contrast, when the barrier height is increased, it is called "reverse bias" that causes decreases in the PV current and reduces it to a very small value (Fig. 4.12).

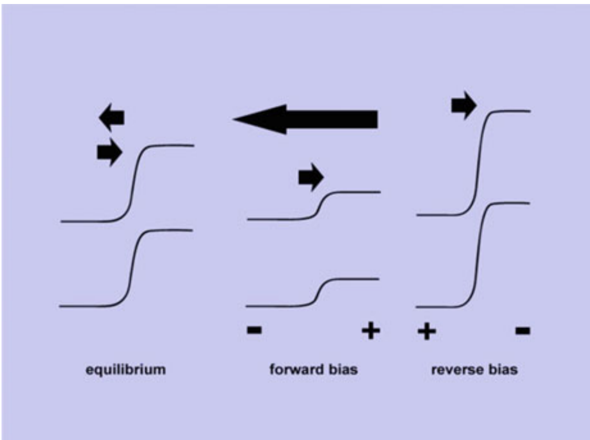


Fig. 4.12 Barriers charges

4.8 The Generation of Electron-Hole Pairs with Light and the Solar Spectrum

Figure 4.13 shows a graph of the wavelengths of the photons of the solar spectrum flow reaching the Earth. The solar spectrum outside the atmosphere has visible waves at its expected peak of black body radiation at 6000 K (sun's surface temperature). A portion of the solar spectrum that flows through the atmosphere is lost when it is absorbed by water vapor and carbon dioxide [7]. Solar energy consists of different frequencies representing wavelengths. If these wavelengths were gathered in one wavelength, the solar cells that are depending on the current technology will have more than 95% efficiency. However, what actually happens is that there are different wavelengths, and only a fraction of the PV module can absorb.

When the photon falls on the surface of the solar cells, it absorbs it and the photon's energy either turns into heat that increases the temperature of the cell or goes to produce the electron from the B_V to get it sent to the C_P. In this way, a hole will be left behind in B_V, which will enhance the absorption process and increase drilling by electron pairs. As the part of the solar spectrum involved in this process is a small part, so the flow of photons converted by solar cell to electron will be about 2/3 of the total flow (Fig. 4.14).

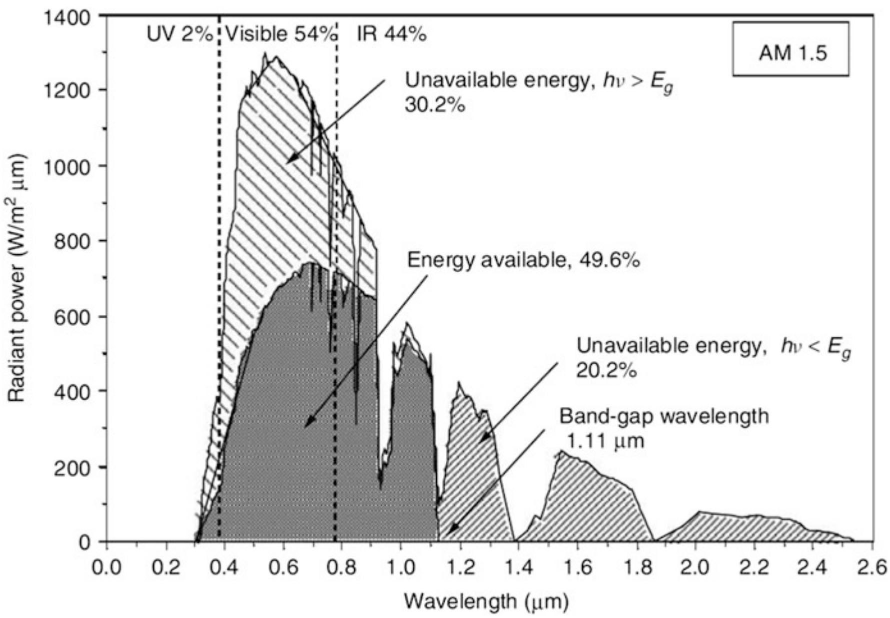


Fig. 4.13 Solar spectrum [25]

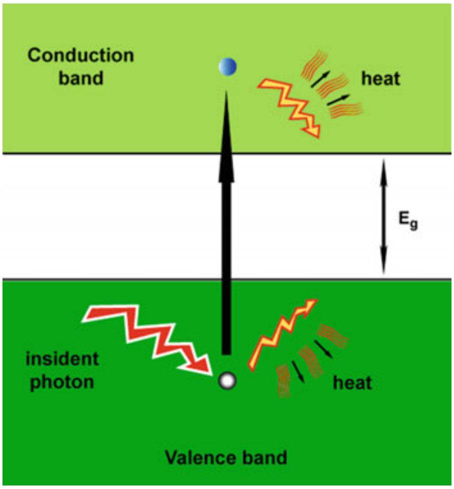


Fig. 4.14 Generation of electron-hole pairs

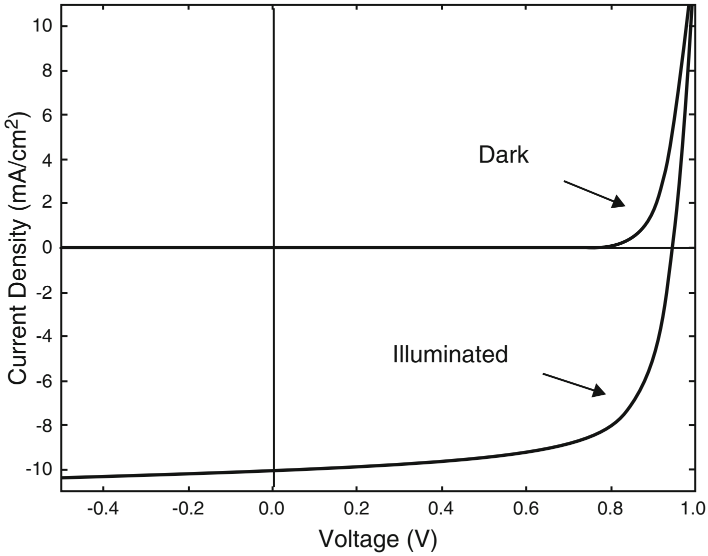


Fig. 4.15 Typical "*I-V* characteristics".

4.9 P-N Junction Electric Currents under External Bias

Figure 4.15 shows the "*I-V* characteristics" (or curve) for a p-n junction [6], recording the current and applying a voltage from negative to positive. At night (dark conditions), the current is not quite zero, and it starts to push electrons over to create a better current. When illuminated, the current is created immediately [1].

The output current of p-n junction is

$$I = I_L - I_o\left[e^{qV/kT} - 1\right] \tag{4.30}$$

- I_L = current generated by light
- q = "electric charge"
- V = voltage
- k = "Boltzmann's constant" = 1.3807×10^{-23}J/K
- The electrical current will follow through the diode (or PV) and when the circuit is "open circuit ($I = 0$). However, when the PV circuit is short circuit, the current passes through the electrical load ($V = 0$).

It is worth to mention here:

1. The open circuit voltage,

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{I_L}{I_o} + 1\right) \tag{4.31}$$

2. No power is generated under short and open circuit, but

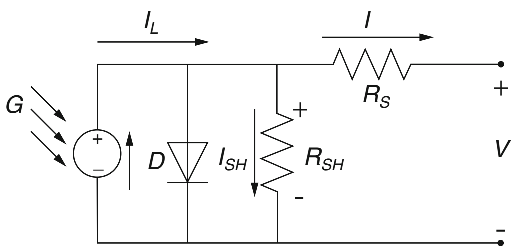
$$P_{max} = V_{max}I_{max} = \text{FF}.V_{oc}I_{sc} \tag{4.32}$$

For the silicon PV technology, the "fill factor" (FF) represents a measure of the real I-V characteristic. The value of p-n junction must be greater than 0.7 to make the solar cell effective. The filling factor decreases by increasing the cell temperature.

4.10 Solar Cell Modeling

Figure 4.16 shows an electrical representation of the solar cell. It is represented as an equivalent circuit with a current source connected in parallel to the diode junction. It fits directly outside the current source with the light intensity absorbed by the cell. The solar cells are inactive during the dark and act as a diode. It produces neither current nor voltage [5]. When light hits solar cells, it generates a diode stream. The

Fig. 4.16 Equivalent circuit of solar cell



diode (D) determines the *I-V* properties of the cell. String resistance (R_s) represents the resistance within each cell, while the extrusion resistance is negligible because it has a large resistance value.

In an ideal solar cell, it is assumed that $R_S = 0$ and $R_{SH} =$ infinity. The net current of the cell could be found by improving Eq. 4.30 as follows:

$$I = I_L - I_o\left[e^{q(V+IR_S)/nkT} - 1\right] \tag{4.33}$$

The photo current (I_L) depends on reference first and second temperatures, T_1 and T_2, respectively, and it is given by,

$$I_L = I_L(T_1) + K_o(T - T_1) \tag{4.34}$$

where

$$I_L(T_1) = I_{SCT1,nom}(G/G_{nom}) \tag{4.35}$$
$$K_o = (I_{SCT2} - I_{SCT1})/(T_2 - T_1) \tag{4.36}$$

where G is the "present solar radiation" and G_{nom} is the "solar radiation at the reference test."

The "saturation current" of the diode I_o is given by,

$$I_o = I_{oT1}(T/T_1)^{3/n} e^{\frac{qv_{qT1}}{nk\left(\frac{1}{T}-\frac{1}{T_1}\right)}} \tag{4.37}$$

where,

$$I_{oT1} = I_{SCT_1}/e^{\frac{qv_{qT1}}{nk\left(\frac{1}{T}-\frac{1}{T_1}\right)}} \tag{4.38}$$

The series resistance of a solar cell is given by,

$$R_S = -\frac{dV}{dI_{VOC}} - \frac{1}{X_V} \tag{4.39}$$

where,

$$X_V = I_{oT_1}\frac{q}{nkT_1}e^{\frac{qv_{OCT1}}{nkT_1}} \tag{4.40}$$

Figure 4.17 shows a typical *I-V* characteristic of a solar cell at a certain ambient irradiation, G, and fixed cell temperature conditions [6]. The load characteristic is a straight line for a resistive load with slope $I/V = 1/R$. The PV power delivered to the electrical load is proportional to the value of resistance.

Figure 4.17 shows that the cell operates in the M-N region of the curve if the load is small, acting as a constant current source approximately equal to the short circuit

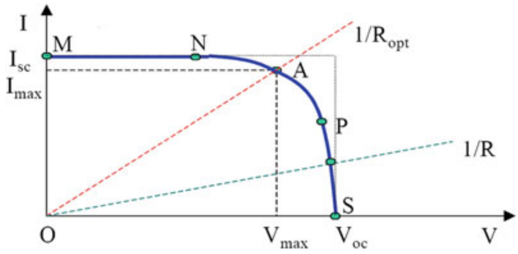


Fig. 4.17 *I-V* characteristic curve of a solar cell

current. In the case of large loads, the cell operates in the P-S regions of the curve and behaves as a constant voltage source which is approximately equal to the voltage of the open circuit.

I_{sc} is the short circuit current, which represents the maximum current generated by a PV panel. This current is produced only when $V = 0$, at the short circuit condition. V_{oc} is the open circuit voltage, which represents the diode's voltage drop when the PV panel current is zero. V_{oc} indicates the PV panel's voltage when there are no light; it is expressed mathematically by:

$$V_{\mathrm{OC}} = \frac{nkT}{q} \ln\left(\frac{I_{\mathrm{L}}}{I_{\mathrm{o}}}\right) = V_{\mathrm{t}} \ln\left(\frac{I_{\mathrm{L}}}{I_{\mathrm{o}}}\right) \tag{4.41}$$

where $V_{\mathrm{t}} = \frac{mkT_{\mathrm{C}}}{q}$ is known as the thermal voltage and T is the absolute cell temperature.

The "maximum power point is at the operating point A in which the power dissipated in the resistive load is at its maximum value" and is given by Eq. 4.32. The maximum efficiency of a solar cell is the "ratio between the maximum power and the incident light power" and is expressed as:

$$\eta = \frac{P_{\max}}{P_{\mathrm{in}}} = \frac{I_{\max} V_{\max}}{AG_{\mathrm{a}}} \tag{4.42}$$

where A is the "area" of the PV module and G_{a} is the radiation.

4.11 The Solar Cell, Module, and Array

In semiconductor the extraction of the generated electric current is done through contacts to the front and rear of cell. The extensively spaced thin strips, or also known as fingers, are created so that light is permitted through. These fingers supply current to the larger bus bar. The cell is covered with an "antireflection coating" (ARC) to minimize light reflection from the top surface. The ARC is made up of a thin layer of dielectric material [24] (Fig. 4.18).

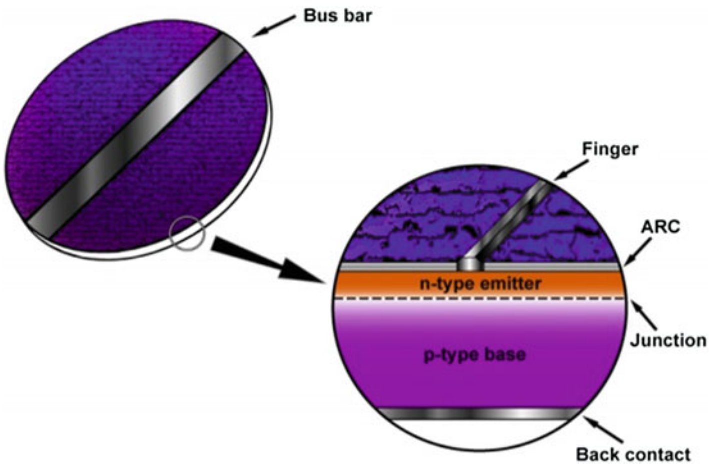


Fig. 4.18 Solar cell

The volt and half produced by one solar cell is not enough to run many applications, which require increased voltage, so the cells are connected in a series. A few strings of cells can be connected in parallel to increase the current generated. These bonded cells and their electrical connections are assembled between the upper layer of the glass or transparent plastic and at a lower level than the plastic metal. The cells are connected to an external frame to increase mechanical strength and provide a way to install the unit. This package is called a PV panel or a PV module. The energy generated from one unit is not enough to make enough energy for many loads, so a number of PV units can be connected in parallel, series, or both, to form rows of panels sufficient to increase output current and/or voltage.

4.12 Photovoltaic Systems

The operational requirements determine the classification, composition, and functionality of the PV systems and also determine how the equipment is connected to other power sources and electrical loads. Photovoltaic systems are classified into separate and connected systems. Figure 4.19 shows stand-alone photovoltaic systems that operate without being connected to an electrical grid and are of the same size designed to generate specific electrical loads from DC or AC [3–26]. As shown in Fig. 4.20, these systems may have their primary power coming from the PV arrays only. If a diesel engine generator or wind generator is used as a backup power source, this system is referred to as a hybrid system, as shown in Fig. 4.21 [27].

The coupler system can be considered as the simplest type of independent PV system. However, the direct coupler system does not include batteries. Therefore, the system operates only in the morning where the hours of sunlight make these systems

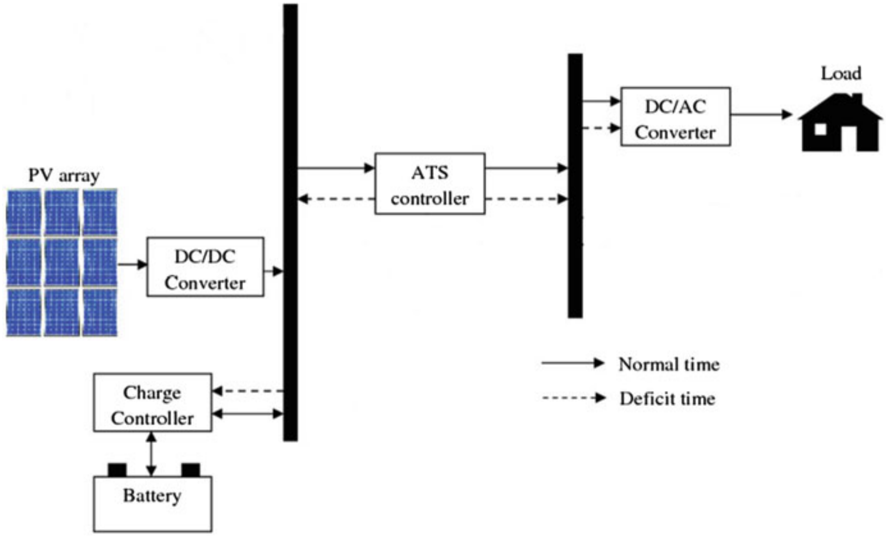


Fig. 4.19 Stand-alone PV system

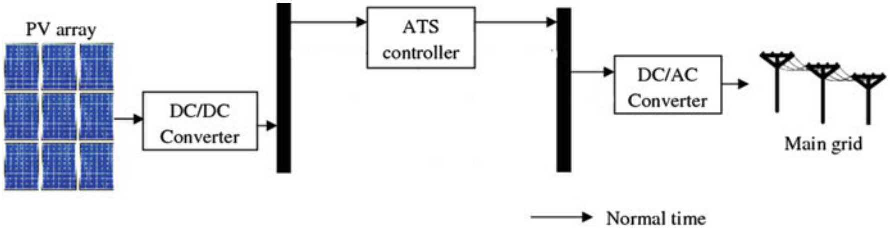


Fig. 4.20 Grid-connected PV system

suitable for common applications such as water pumps, ventilation fans, and small circulation pumps for solar water heating systems. Matching electric load resistance to maximum output power is an important issue when designing direct coupling systems. To take advantage of the maximum power output of the photovoltaic system, use a DC to convert to DC, or the so-called maximum power point tracker (MPPT). Most PV systems use batteries to store generated energy, making these systems safer and their output current more stable.

The energy generated by photovoltaic modules depends mainly on the intensity of the solar radiation to which the panels are exposed. The amount of energy that is received depends on the inclination angle of the PV unit installed. So, the energy generated by the PV system increases when the panels track the sun. These systems were used in Europe and resulted in relatively high radiation gains in high brightness

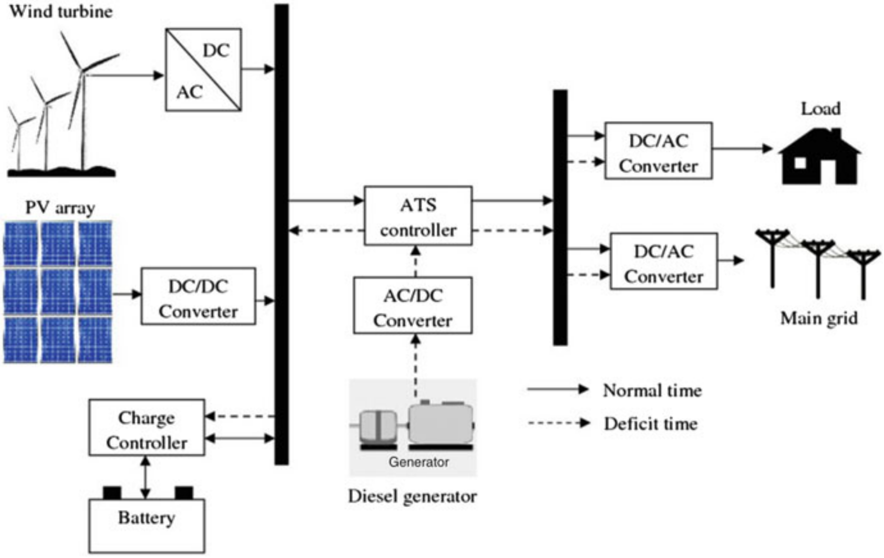


Fig. 4.21 "Hybrid PV/wind/diesel generator" system

days. A large proportion of direct radiation can cause gains of up to 50% in bright summer days, whereas in the winter these gains reach 300% compared to fixed wall systems [28]. Sun tracking causes a higher increase in system productivity during the summer and absolute gains in the winter.

4.13 Design and Optimization of Photovoltaic Systems

Solar photovoltaic (PV) and hybrid systems play a major role in the electric provisioning of electrical sectors in rural, isolated, and desert area. For the hybrid systems, electricity production majorly depends on auxiliary sources such as diesel and natural gas generators. Combinations of different energy sources form these hybrid systems such as PV/battery, wind/battery, wind/PV/battery, wind/PV/diesel/battery. . . .

However, the main criterion for the design of the PV/battery system is its ability to meet the required electrical load with a high level of security. In the literature many optimal methods of PV/battery systems are mentioned. The design and control of photovoltaic systems can be divided into three categories: intuitive, numerical (simulation) techniques, and analytical techniques, as well as there are the individual methods, as shown in Fig. 4.22 [29].

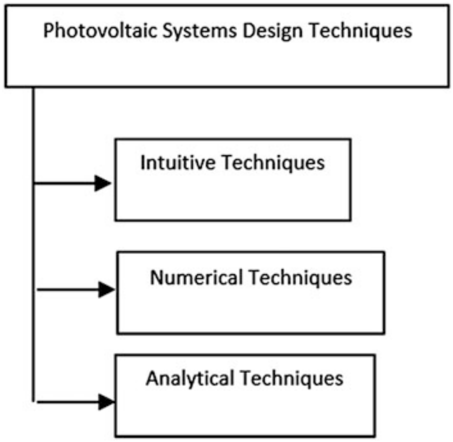


Fig. 4.22 PV system design techniques

4.13.1 Intuitive Technique

The intuitive technique is defined as "a simplified calculation of the size of the system carried out without establishing any relationship between the different subsystems or taking into account the random nature of solar radiation."

When the requirement is to design a photovoltaic power system, the first step is to estimate the energy demand and loads required by multiplying the capacity of each individual device by the average number of hours of use. Twenty percent of the output must be added, which represents the losses caused by the wires [28], the DC conversion to AC, the panels dirtiness, etc. The description of loads, whatever the AC or DC, should be included in a worksheet showing the current load, daily work cycle, weekly work cycle, energy conversion efficiency, nominal voltage systems, and AMP/hr. load. As for the devices that are frequently used, the designer must develop alternatives to energy conservation, identify large and/or variable loads, and determine whether they can be eliminated or changed to work from another power source. As an example, LED lamps should replace incandescent lamps. Because this light provides higher levels of light with much lower energy consumption, which is exactly what meant by the concept of the energy efficiency. Therefore, the operating voltage and current of a separate PV system must be selected based on the required loads. If the system voltage is equal to the largest load voltage, these loads can be directly related to the system output, although it is recommended that the current in the source be less than 20 and not exceed 100 amperes for any part of the system. Maintaining the recommended levels allows the use of standard and normally available electrical equipment and wires safely.

When loads require AC power, a study of available inverter characteristics should precede the selection of DC system voltage [3]. The optimal inventor should be selected to meet the load requirements and maintain a constant current below 100A, indicating the importance of this selection and its implications for the cost and performance of the system as well. The best procedure is to deal with the power and efficiency of units operating in high voltages, usually a 48 V unit is more efficient than a 12 V unit. Precise information about the inventors to be used, availability, cost, and capabilities available from many manufacturers must be obtained before deciding which system to use. It is worth mentioning that the basis in subsystems is storage as the PV module has to be larger storage with increased voltage. For example, a 24 V system contains two sets of photovoltaic modules that are connected to the system's configuration, although the high voltage needs an operational low current to produce the same energy. Therefore, the high voltage leads to the need for larger wire size, increasing the cost and increasing the volume of switches, connectors, and valves. It can be said that the information already available on components, cost, and switches is of great importance in the design of a high-quality PV system [4].

The calculations of the variable parameters of the stand-alone system shown in Fig. 4.23 require the assistance of some formulas as the following:

$$P_{\mathrm{PV}} = \frac{E_{\mathrm{L}}}{\eta_{\mathrm{S}}\eta_{\mathrm{inv}}\mathrm{PSH}} S_{\mathrm{f}} \tag{4.43}$$

where E_{L} represents the daily energy consumption, *PSH* is the peak sun hours, η_{inv} and η_{S} are the efficiencies of the system components, and S_{f} is the safety factor that represents PV cell temperature losses and the compensation of resistive losses [30–33].

On the other hand, the battery capacity can be calculated by

$$C_{\mathrm{Wh}} = \frac{E_{\mathrm{L}} \times D_{\mathrm{Autonomus}}}{V_{\mathrm{B}}\mathrm{DOD}\eta_{\mathrm{B}}} \tag{4.44}$$

where η_{B} is the battery efficiency, and V_{B} is the battery voltage, while *DOD* is the permissible depth of discharge rate of a cell. Besides, the energy of a PV array can be calculated using the solar radiation intensity and ambient temperature:

$$E_{\mathrm{PV}}(t) = A_{\mathrm{PV}}E_{\mathrm{sun}}(t)\eta_{\mathrm{wire}}\eta_{\mathrm{PV}}\eta_{\mathrm{inv}} \tag{4.45}$$

where A_{PV} is the PV array's area and E_{sun} is the solar energy. η_{wire} and η_{PV} represent the wires' efficiency and the PV conversion and inverter conversion, respectively.

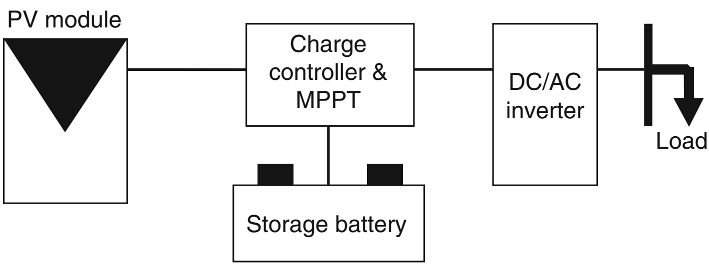


Fig. 4.23 Typical PV system components

However, the temperature has an impact on the conversion efficiency of a PV panel evaluated by:

$$\eta_{\mathrm{PV}}(t) = \eta_{\mathrm{PV_{Ref}}}[1 - \beta_{\mathrm{T}}(T_{\mathrm{c}}(t) - T_{\mathrm{C_{Ref}}})] \tag{4.46}$$

where η_{pvRef} and β_{T} are the "reference PV module conversion" and "temperature coefficient" efficiencies, respectively. T_{cref} and T_{c} are the "reference cell" and "cell" temperatures, respectively. The panel temperature is calculated using the ambient temperature [34–36]:

$$T_{\mathrm{c}}(t) - T_{\mathrm{ambient}} = \frac{T_{\mathrm{Test}}}{800} G(t) \tag{4.47}$$

where T_{Test}, T_{ambient}, and G are the temperature during testing, the ambient temperature, the PV module and solar radiation, respectively.

The annual capacity factor is defined as "the ratio of actual annual energy output to the amount of energy the PV array would generate if it operates at full rated power (P_{r}) for 24 h per day for a year":

$$\mathrm{CF} = \mathrm{YF}/8760 = E_{\mathrm{PVannual}}/(P_{\mathrm{R}} \times 8760) \tag{4.48}$$

Meanwhile, the yield factor is defined as "the daily, monthly, or annual net AC energy output of the system divided by the peak power of the installed PV array" [37–39].

$$\mathrm{YF} = E_{\mathrm{PV}}(\mathrm{kWh/year})/\mathrm{PV_{WP}}\left(\mathrm{kW_p}\right) \tag{4.49}$$

4.13.2 A Numerical Technique

Numerical technology simulates the system considering each time period (usually 1 h or 1 day) to calculate the system's energy balance and battery load status. The numerical calculation is oriented to achieve the highest possible accuracy compared to the intuitive technique and to ensure that the energy reliability is measured as accurately as possible. The PV system is designed and modeled today using a large number of programs that estimate and calculate the energy produced for a given PV system with its various components. Some of these software are SOLCEL, Evans and Facinelli Model, PVSS, PVForm, PVSIM, Sandia Photovoltaic Array Performance Model, Sandia Inverter Performance Model, PVDesignPro, Solar Advisor Model, PVSYST, Five-Parameter Array Performance Model, RETScreen Photovoltaic Project Model, PVWatts, Polysun, PV F-Chart, SolarPro, PVSol, Clean Power Estimator, INSEL, OnGrid, PVOptimize, Solar Estimate, CPF Tools, HybSim, SOLSTOR, Hybrid2, Hysim, RETScreen, UW-Hybrid (TRNSYS), RAPSIM, PVToolbox, IPSYS, SOMES, Dymola/Modelica, HySys, PV.MY, REPS.OM, and HOMER [31, 32].

4.13.3 An Analytical Technique

The analytical technique of sizing the PV/battery system is achieved through describing it using equations as a function of the reliability to develop. This method represents the simplest design and calculation of the size of the PV system, and its simplicity can be considered a great advantage for it. What is wrong with this technique is that the equations adopted depend on the conditions of the location. The difficulty in obtaining the coefficients of this equation can be considered another disadvantage of this technique [33–35].

4.14 PV Systems Economic

In this section we will identify some expressions and terms related to the economics of PV systems. The economic variables that represent the importance of PV are the capital cost (total cost of PV installation), feeding in tariffs, energy recovery time (EBET), and electricity prices. Other expressions related to the PV systems' economy are the same as the investments in renewable energies [2]. The PV system cost is usually measured by price per peak watt (USD/Wp or €/Wp, e.g.,). Peak watt is defined as "the power at standard test conditions (STC) (solar irradiance 1000 W/m^2, AM of 1.5, and temperature 25°C)." Photovoltaic system costs can be divided into module costs and public service costs. The costs of any PV array represent 40–60% of the total photovoltaic system costs. Half of this value is the cost of purchasing PV units, photovoltaic support structures, inverter, and electrical cables, and the rest represents equipment and installation. BOSS costs and installation costs can vary greatly. For example, total installation costs become high when site preparation costs, system design and engineering, laying foundation, permitting, as well as work installation and assembly are high [4]. The cost of the life cycle of the PV system may also include system design and engineering costs, site setup, installation work, permits, operating, and maintenance costs. The lifetime of photovoltaic systems ranges from 20 to 25 years [27, 36–39].

Capital cost, replacement cost, maintenance cost, and salvage value represent the variable components for calculating *LCC*. Capital cost represents the initial cost spent on purchasing PV panels, mechanical structures supporting photovoltaic modules, batteries, charging controller, inverter, circuit breakers, special cables, and installation charges. The replacement cost is the cost paid by the consumer to replace the different parts for the end of their operating life such as batteries, charge controller, inverter, and cables. Batteries must be replaced once every 6 years, while it is preferable to replace the charge controller, inverter, and cable every 12 years. The annual maintenance cost is the cost that the consumer pays annually. Maintenance can prevent breakage or malfunction of the system and must be done by a professional operator. The rescue value represents the money that will be obtained when solar units are disposed of for the end of their life cycle. To calculate the sum, all the above costs are converted to the current equivalent [3, 40].

The criteria for evaluating the system economically are the recovery period and the cost of energy. As is known, photovoltaic units account for 40% of the PV investment, the rest is paid for the support structure, the inverter, cables, equipment, and installation, which represent the remaining part of the investment. The *LCC* of a PV system may also include costs for system design, site preparation, installation labor, permits, and operation and maintenance costs [30]. The life cycle cost can be evaluated using the following equation:

$$LCC = C_{\text{capital}} + \sum_{1}^{n} C_{\text{O\&M}}.R_{\text{PW}} + \sum_{1}^{n} C_{\text{replacement}}.R_{\text{PW}} - C_{\text{salvage}}.R_{\text{PW}} \quad (4.50)$$

The components needed for calculating *LCC* are capital cost (C_{capital}), replacement cost ($C_{\text{replacement}}$), maintenance cost ($C_{\text{O \& M}}$), and salvage value (C_{salvage}). R_{PW} represents the present worth of each factor which is calculated using the future sum of money (F) in a given year (N) at a given discount rate (I) [41–45]:

$$R_{\text{PW}} = F/(1 + I)^{N} \quad (4.51)$$

After calculating *LCC*, the cost of energy is calculated using [26]:

$$\text{CoE} = LCC/\sum_{1}^{n} E_{\text{PVannual}} \quad (4.52)$$

where E_{PVannual} is the annual energy production of the PV system, while n is the system lifetime in years.

Finally, the payback period can be calculated by [34]:

$$PBP = C_{\text{capital}}(USD)/[E_{\text{PVannual}}(\text{kWh/year}) \times \text{CoE}(USD/\text{kWh}) \times R_{\text{PW}}] \quad (4.45)$$

4.15 Photovoltaic Applications

The gift that PV technology has is it being a source of energy that satisfies the electrical demand by direct conversion of sunlight into electricity without emitting pollution or harming the environment. In addition, it does not have any moving parts like the other conventional energy sources such as fossil fuels (i.e., oil, gas, etc.), which still form most of global energy sources. PV systems can be implemented for a variety of applications which range all the way from little toys to industrial processes, scaling small, medium, and large. Three categories can be used to classify PV applications, namely: utility interactive, stand-alone, and solar tracking systems [46–49].

The utilities' interactive systems are attractive and useful because of the significant reduction in the bill of electricity consumption by reducing the amount of electricity consumed from the grid, especially during the hours of maximum demand, which coincides with the peak hours of solar radiation. The use of electricity produced from PV systems during these hours will reduce the maximum consumption cost that consumers will pay to electricity companies [2, 50–56].

The stand-alone configuration of PV systems contains a wide range of applications. A stand-alone system does not relate to the facility, and it is useful to independent entities in particular, which include different applications of independent PV systems such as [35–38]:

Lighting The use of photovoltaic systems to provide lighting for lighting panels, public use facilities, signs of highway information, trains lighting cabin, homes, pavements, parking spaces, anchors, and holiday cabin are common these days [57, 58].

Communications Integration of PV systems to supply television, radio, and phone signals over long distances, which require amplification. This function, amplification, is performed by repeater stations or relay towers. The optimal location for the relay towers will be the maximum possible height [59]. As there are no power lines for the facilities because the transfer of traditional heavy generators is expensive and difficult at the same time. The installation of low weights and easy to transport solar cells to operate information transmitters for travelers, laptop systems, mobile radio systems, cell phones, and emergency call boxes is the best and cheapest solution [60, 61].

Remote Site Electrification When residential complexes are in remote areas or at difficult terrain, the use of photovoltaic systems makes these autonomous complexes self-equipped with electric power. Examples include the processing of electricity produced by rural household systems, remote farm and clinic workshops, visitor centers in parks and holiday cabins, garden guard sites, fishing lodges, village and car electrification, remote search facilities, beach facilities, convenience spots on highways, camps, and military test areas [62, 63].

Remote Monitoring For regular monitoring and other functions required to be performed at sites far from utility connection and for scientific research. The advantages of photovoltaic systems make it an effective solution for these situations. They can be efficiently used to operate the weather station for scientific research in remote locations, monitoring meteorological information, seismic recording, structural conditions, monitoring of irrigation systems in remote areas, and traffic conditions on highways [64, 65].

Signs and Signals PV systems can be used to operate electrical devices and equipment that are located in difficult terrain or in remote areas, which are difficult to connect to the grid. When electricity is not economically feasible because of the difficulty of terrain or remote location makes it impossible to reach the grid, photovoltaic systems are a source of reliable and stable power supply for these important applications. These systems include warning alarms such as sirens, highway warning signs, navigation beacons, aircraft warning lights, rail signals, and buoys [66–68].

Water Pumping and Control PV systems are an ideal choice for water pumping applications that use pumps for watering, drinking, drinking water for camps, as well as water supplies to remote villages. These pumps are usually fed from conventional diesel generators, but once supplied by a PV system, the noise, pollution, and constant maintenance of the conventional sources will be eliminated [69–71].

Charging Vehicles' Batteries PV systems can be used to charge electric power for batteries directly (low charge), for vehicles' slightly used batteries, which maintains a high charge in the battery. PV systems can also be used to charge multiple equipment batteries such as snow removal equipment, agricultural machinery such as harvesters or tractors, and fire-fighting equipment. These systems are also used for direct charging of boats and recreational vehicle batteries [72, 73].

Disaster Relief Applications The cities are seriously affected, and there is a complete interruption of electric power sometimes for long periods, which affects the stability of facilities and sometimes failure due to natural disasters such as floods, earthquakes, and hurricanes. In such emergency circumstances, portable photovoltaic systems provide an important option that provides electricity for street lighting, personal lighting, operation of alarms, energy saving for communications equipment, medical supplies, cooling, water purification, and water pumping [74].

Cathodic Protection Corrosion occurs with metallic equipment when they are exposed to water and soils due to electrolytic action, where metals lose ions which lead to this corrosion when metal are exposed to an electrolyte. A small DC voltage could be applied to the metal to protect it from ion loss, which is referred to as cathodic protection. If any device is used to assist the power supply for cathodic protection, the electrical voltage must be converted from AC to DC currents. While the use of PV systems, which is a technique that produces the necessary DC voltage efficiently and inexpensively. The importance of cathodic protection lies in applications it protects such as tanks, pipes, buildings, bridges, sidewalks, and wells [75, 76].

Refrigeration PV systems offer electrical supply for the storage of vaccines and medicines transferred to remote areas, which must maintain a certain temperature to avoid damage [77].

Consumer Products PV systems can be used in a variety of applications that are commercially available to consumers nowadays. These applications include external lights, batteries, lanterns, calculators, clocks, radios, golf carts, recreational vehicles, television sets, security systems, and fans and gate openings [78, 79].

References

1. DaRose AV (2005) Fundamentals of renewable energy processes. Elsevier, New York
2. Kazem HA (2012) Renewable and sustainable energy, principles and applications", 1st edn, 978-3-659-46238-2 LAP LAMBERT Academic Publishing, Germany

3. Kazem HA, Khatib T, Sopian K (2013) Sizing of a standalone photovoltaic/battery system at minimum cost for remote housing electrification in Sohar, Oman. Energy Build 6C:108–115
4. Kazem HA, Khatib T (2013) Techno-economical assessment of grid connected photovoltaic power systems productivity in Oman. Sustain Energy Technol Assess 3:61–64
5. Kazem HA, Khatib T (2013) Photovoltaic power system prospective in Oman, technical and economic study. 1st edn, ISBN: 978-3659372957, LAP LAMBERT Academic Publishing, Germany
6. Markvart T (2000) Solar electricity,2nd edn. University of Southampton, Wiley
7. Understanding Renewable Energy Systems (2005) Volker Quaschning, Carl Hanser Verlag GmbH & Co KG
8. Smee A (1849) Elements of electro-biology: or the voltaic mechanism of man; of electro-pathology, especially of the nervous system; and of electro-therapeutics. Longman, Brown, Green, and Longmans, London, p 15
9. The Nobel Prize in Physics (1921) Albert Einstein, Nobel Price official (www.nobelprize.org)
10. Carlson DE, Wronski CR (1976) Amorphous silicon solar cells. Appl Phys Lett 28:671–673
11. Handy RJ (1967) Theoretical analysis of the series resistance of a solar cell. Solid State Electron 10:765
12. Barnett A et al (2007) Milestones toward 50% efficient solar cell modules. In: 22nd photovoltaic eurbean solar energy conference, Milan-Italy
13. European Directory of Renewable Energy (1991) London; James & James Science Publishers
14. Boyle G (2004) Energy systems and sustainability: power for a sustainable future. Open University, Oxford UK Press
15. Hill R (1999) Prospects for photovoltaics. Energy World 208:8–11, original data updated by Hynes K. and Hill R
16. IEEE Standard 1262–1995 (1995) Recommended practice for qualification of photovoltaic (PV) modules. IEEE, Piscataway
17. Xiao W, Ozog N, Dunford WG (June 2007) Topology study of photovoltaic Interface for maximum power point tracking. IEEE Trans Ind Electron 54(3):1696–1704
18. Kazem H, Al-Rawahi B, Al-Shabibi G, Al-Nabhani T (2010) Solar energy in Sultanate of Oman. International Renewable Energy Congress IREC2010, Sousse Tunisia, November 5(7):36–39
19. National Renewable Energy Laboratory (2008) NREAL: NREL Solar Cell Sets World Efficiency Record at 40.8 Percent. 21 October 2008
20. Ting Chung Y, Chien TS (2009) Analysis and simulation of characteristics and maximum power point tracking for photovoltaic systems, In: International Conference on Power Electronics and Drive Systems, PEDS, Taipei, Taiwan, pp. 1339–1344
21. Photon International (February, 2009 and 2010)
22. Herasimenka SY (2013) Large Area Ultrapassivated Silicon Solar Cells Using Heterojunction Carrier Collectors, Ph D Thesis, Arizona State University, USA
    Proceedings of the IEEE PVSC (US), the European PVSEC (EU), and the Pacific Rim PVSEC (Asia and Australia)
23. The US PV industry roadmap through 2030 and beyond (2003) Available at: https://www.nrel.gov/docs/gen/fy03/30150.pdf
24. Kazmerski LL (2011) Photovoltaic: history, technology, markets, manufacturing, applications, and outlook. In: 84th international seminar in brighton, renewable energy policy, security, electricity, sustainable transport, Water Resources/Management and Environment, Brighton, 3–9 July 2011
25. Gilbert M (2004) Renewable and efficient electric power systems. Wiley, Hoboken/New Jersey
26. Kazem HA, Tamer Khatib KS, Elmenreich W (2014) Performance and feasibility assessment of a 1.4kW roof top grid-connected photovoltaic power system under desertic weather conditions. Energy Building 82:123–129

27. Kazem HA, Khatib T (2013) A novel numerical algorithm for optimal sizing of a photovoltaic/wind/diesel generator/battery microgrid using loss of load probability index. Int J Photoenergy 2003:8
28. Mousazadeh H, Keyhani A, Javadi A, Mobli H, Abrinia K, Sharifi A (2009) A review of principle and sun-tracking methods for maximizing solar systems output. Renew Sustain Energy Rev 13:1800–1818
29. Kazem HA, Al-Aisaee AMS, Sopian K, Albusaidi AS, Albadi MH (2014) Design and evaluation of photovoltaic systems using different techniques. In: International conference on advances in electrical and electronics engineering (ICAEEE'2014), January 15–16, 2014 Kuala Lumpur (Malaysia)
30. Kazem HA, Khatib, T, Alwaeli AAK (2013) Optimization of photovoltaic modules title angle for Oman. In: 7th IEEE international power engineering and optimization conference PEOCO2013, Malaysia, 3–4 June 2013, pp 700–704
31. Endecon Engineering (2001) A guide to photovoltaic system design and installation. California Energy Commission, Version 1.0 June 14, USA
32. Klise GT, Stein JS (2009) Models used to assess the performance of photovoltaic systems. Sandia National Laboratories, SANDIA REPORT, SAND2009-8258, Unlimited Release, USA, Printed December
33. Kazem HA, Yousif J (2017) Comparison of prediction methods of photovoltaic power system production using a measured dataset. Energy Convers Manag 148:1070–1081
34. Al-Waeli AHA, Chaichan MT, Kazem HA, Sopian K (2017) The use of different types of nanofluids (Al2O3, CuO, and SiC) to enhance photovoltaic thermal PV/T collectors. Energy Convers Manag 148:963–973
35. Yousif J, Kazem HA, Boland J (2017) Predictive models for photovoltaic electricity production in hotweather conditions. MDPI-Energies 10(7):971
36. Al-Waeli AH, Kazem HA, Sopian K Chaichan MT (2017) Techno-economical assessment of grid connected PV/T using nano particles and water as base-fluid systems in Malaysia. Int J Sustain Energ:1–18. https://10.1080/14786451.2017.1323900
37. Kazem HA, Albadi MH, Al-Waeli AHA, Al-Busaidi AH, Chaichan MT (2017) Techno-economic feasibility analysis of 1 MW photovoltaic grid connected system in Oman. Case Stud Therm Eng 10:131–141
38. Ali H, Al-Waeli KS, Kazem HA, Chaichan MT (2017) Photovoltaic thermal PV/T systems: a review. Int J Comput Appl Sci (IJOCAAS), UK 2(2):62–67
39. Sulaiman SI, Rahman TKA, Musirin I, Shaari S, Sopian K (2012) An intelligent method for sizing optimization in grid-connected photovoltaic system. Sol Energy 86(7):2067–2082
40. Beser E, Arifoglu B, Camur S, Beser EK (2010) A grid-connected photovoltaic power conversion system with single-phase multilevel inverter. Sol Energy 84(12):2056–2067
41. Kim JY, Jeon GY, Hong WH (2009) The performance and economical analysis of grid-connected photovoltaic systems in Daegu, Korea. Appl Energy 86(2):265–272
42. Mondol JD, Yohanis YG, Norton B (2007) Comparison of measured and predicted long term performance of grid a connected photovoltaic system. Energy Convers Manag 48 (4):1065–1080
43. Al-Hasan AY, Ghoneim AA, Abdullah AH (2004) Optimizing electrical load pattern in Kuwait using grid connected photovoltaic systems. Energy Convers Manag 45(4):483–494
44. Al-Ismaily HA, Probert D (1998) Photovoltaic electricity prospects in Oman. Appl Energy 59 (2–3):97–124
45. Al-Badi AH, AL-Toobi M, AL-Harthy S, Al-Hosni Z, AL-Harthy A (2012) Hybrid systems for decentralized power generation in Oman. Int J Sustain Energy 31(6):411–442
46. Al-Badi AH, Albadi MH, Al-Lawati AM, Malik AS (2011) Economic perspective of PV electricity in Oman. Energy 36:226–232
47. Kazem HA, Khatib T (2013) Techno-economical assessment of grid connected photovoltaic power systems productivity in Oman. Sustainable Energy Technologies and Assessments 3:61–64

48. Kazem HA, Khatib T, Sopian K, Elmenreich W (2014) Performance and feasibility assessment of a 1.4kW roof top grid-connected photovoltaic power system under desertic weather conditions. Energy and Building 82:123–129
49. Katsumata N, Nakada Y, Minemoto T, Takakura H (2011) Estimation of irradiance and outdoor performance of PV modules by meteorological data. Sol Energy Mater Sol Cells 95:199–202
50. Chow TT, Hand JW, Strachan PA (2003) Building-integrated PV and thermal applications in a subtropical hotel building. Appl Therm Eng, Elsevier publisher 23:2035–2049
51. Kazem HA, Chaichan MT (2015) Effect of humidity on PV performance based on experimental study. Int J Appl Eng Res 10(23):43572–43577
52. Mukund R. Patel (1999) Wind and Solar Energy. CRC Press LLC
53. Kazem HA, Chaichan MT (2016) Experimental analysis of the effect of dust's physical properties on photovoltaic modules in northern Oman. Sol Energy, Elsevier publisher 139:68–80
54. Kymakis E, Kalykakis S, Papazoglou T (2009) Performance analysis of a grid connected Photovoltaic Park on the island of Crete. Energy Convers Manag 50:433–438
55. Kazem HA, Khatib T, Kopian K (2013) Sizing of a standalone photovoltaic/ battery system at minimum cost for remote housing electrification in Sohar, Oman. Energy and Building 6C:108–115
56. Ali Sayigh (2017) Practical Photovoltaic for Sustainable Electricity and Buildings. 1st Edition, Springer, ISBN10 3319392786, ISBN13 9783319392783, Switzerland
57. Kazem HA, Chaichan MT, Al-Shezawi IM, Al-Saidi HS, Al-Rubkhi HS, Al-Sinani JK, Al-Waeli AHA (2012) Effect of humidity on the PV performance in Oman. Asian Trans Eng 2(4):29–32
58. Kazem AA, Chaichan MT, Kazem HA (2014) Effect of dust on photovoltaic utilization in Iraq: review article. Renew Sust Energ Rev 37:734–749
59. Chaichan MT, Mohammed BA, Kazem HA (2015) Effect of pollution and cleaning on photovoltaic performance based on experimental study. Int J Sci Eng Res 6(4):594–601
60. Kazem HA, Chaichan MT, Saif SA, Dawood AA, Salim SA, Rashid AA, Alwaeli AA (2015) Experimental investigation of dust type effect on photovoltaic systems in north region, Oman. Int J Sci Eng Res 6(7):293–298
61. Kazem HA, Al-Waeli AHA, Al-Mamari ASA, Al-Kabi AHK, Chaichan MT (2015) A photovoltaic application in car parking lights with recycled batteries: a techno-economic study. Aust J Basic Appl Sci 9(36):43–49
62. Kazem HA, Al-Waeli AHA, Chaichan MT, Al-Mamari AS, Al-Kabi AH (2016) Design, measurement and evaluation of photovoltaic pumping system for rural areas in Oman. Environ Dev Sustain. https://doi.org/10.1007/s10668-016-9773-z
63. Chaichan MT, Kazem HA (2016) Experimental analysis of solar intensity on photovoltaic in hot and humid weather conditions. Int J Sci Eng Res 7(3):91–96
64. Chaichan MT, Kazem HA, Mahdy AMJ, Al-Waeely AA (2016) Optimal sizing of a hybrid system of renewable energy for lighting street in Salalah-Oman using Homer software. Int J Sci Eng Appl Sci (IJSEAS) 2(5):157–164
65. Chaichan MT, Kazem HA, Mahdy AMJ, Al-Waeely AA (2016) Optimization of hybrid solar PV/ diesel system for powering telecommunication tower. IJESET 8(6):1–10
66. Kazem HA, Al-Waeli AHA, Chaichan MT, Al-Mamari AS, Al-Kabi AH (2016) Design, measurement and evaluation of photovoltaic pumping system for rural areas in Oman, Environment Development and Sustainability. https://doi.org/10.1007/s10668-016-9773-z
67. Kazem HA, Chaichan MT (2016) The impact of using solar colored filters to cover the PV panel on its outcomes. Bulletin J 2(7):464–469. https://doi.org/10.21276/sb.2016.2.7.5
68. Ali H (2016) Al-Waeli, Hussein a Kazem, Miqdam T Chaichan, review and design of a standalone PV system performance. Int J Comput Appl Sci IJOCAAS 1(1):1–6
69. Kazem HA, Chaichan MT (2016) Design and analysis of standalone solar cells in the desert of Oman. J Sci Eng Res 3(4):62–72

70. Chaichan MT, Kazem HA (2016) Energy conservation and management for houses and building in Oman-case study. Saudi J Eng Technol 1(3):69–76
71. Kazem HA, Chaichan MT (2016) Effect of environmental variables on photovoltaic performance-based on experimental studies. Int J Civ, Mech Energy Sci (IJCMES) 2(4):1–8
72. Al-Waeli AH, El-Din MMK, Al-Kabi AHK, Al-Mamari A, Kazem HA, Chaichan MT (2017) Optimum design and evaluation of solar water pumping system for rural areas. Int J Renew Energy Res 7(1):12–20
73. Chaichan MT, Kazem HA (2017) Effect of sand, ash and soil on photovoltaic performance: an experimental study, international journal of scientific. Eng Sci 1(2):27–32
74. Al-Waeli AHA, Sopian K, Chaichan MT, Kazem HA, Hasan HA, Al-Shamani AN (2017) An experimental investigation on using of nano-SiC-water as base-fluid for photovoltaic thermal system. Energy Conserv Manage 142:547–558
75. Al-Waeli AHA, Sopian K, Kazem HA, Chaichan MT (2017) PV/T (photovoltaic/thermal): status and future prospects. Renew Sustain Energ Rev 77:109–130
76. Al-Waeli AH, Sopian K, Chaichan MT, Kazem HA, Ibrahim A, Mat S, Ruslan MH (2017) Evaluation of the nanofluid and nano-PCM based photovoltaic thermal (PVT) system: an experimental study. Energy Convers Manag 151:693–708
77. Kazem HA, Al-Badi HAS, Al Busaidi AS, Chaichan MT (2017) Optimum design and evaluation of hybrid solar/wind/diesel power system for Masirah Island. Environ Dev Sustain 19 (5):1761–1778
78. https://doi.org/10.1007/s10668-016-9828-1
79. Al-Waeli AHA, Chaichan MT, Kazem HA, Sopian K (2017) Comparative study to use nano-(Al2O3, CuO, and SiC) with water to enhance photovoltaic thermal PV/T collectors. Energy Convers Manag 148(15):963–973

Chapter 5
Environmental Conditions and Its Effect on PV Performance

5.1 Introduction

As the photovoltaics are fixed outdoor exposed to external meteorological conditions, which vary from one area to another, the atmospheric condition can be considered as the major factor in the impressive performance of the cells. Therefore, the efficiency and productivity of the PV cell vary from one location to another. The experts and photovoltaic manufacturers have identified parameters at which the PV modules give the maximum performance. These parameters are the solar intensity of 1000 W/m^2, a temperature of 25 °C, and the air mass of 1.5. These air requirements are limited, and their presence together may be difficult if not impossible, for every area of their own conditions, which may increase or decrease compared to these requirements.

In the next paragraphs, the main environmental parameter will be discussed for Iraq conditions.

5.2 The Effect of Solar Radiation on PV Modules Performance

Solar energy is a free, clean energy, and it is abundant in most places throughout the year. This energy is a small portion of the sun's energy dropped on the Earth's surface. It is essential for living lives. Also, it can be employed in useful applications, such as heating, ventilation, exciting electrons in a photovoltaic cell, as well as photosynthesis. The efficient harness for solar energy usage is very important nowadays where the high fossil fuel costs accompanied with environmental pollution resulted from the use of these fossil fuels [1].

The nearly parallel incident beam of sunrays referred to as extraterrestrial radiation fluctuates about 7% during a year (from 1412.0 W/m^2 in January to 1321.0 W/m^2

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in July). This difference is due to the changes in the distance between the earth and the sun [2]. The solar constant is unsteady with time due to the fluctuation in the solar radiation. The mean solar constant is varied with about $\pm$ 1 W/m^2 during a typical sun cycle of 11 years as mentioned by Refs [3]. Gueymard [4] revealed that the actual best estimate of the average solar constant is GSC = 1366.1 W/m^2 depending on the data collected over 25 years from Earth and space.

When the solar radiation passes through the Earth's atmosphere, a part of this incident radiation is wasted by absorption and scattering processes by air molecules. Only the direct or beam radiation that is not scattered or reflected reaches the Earth's surface directly. The direct radiation reaches the Earth's surface without any interactions with particles in the atmosphere. Diffuse radiation scatters from the solar beam due to Rayleigh scattering process by gases and aerosols (as dust particles, sulfate particles, soot, sea salt particles, pollen, etc.). Reflected radiation reflects from Earth's surfaces [5]. The solar radiation subjugates to a complex process while transferring through the atmosphere that changes its flux spectral distribution. The scattered radiation that reaches the Earth's ground is known as the diffuse radiation. Also, there is the albedo, that is, the fraction of radiation that hits the ground and reflects back to the atmosphere [6]. These three parts of solar radiation power micrometeorological processes on Earth like sensible heat flux, air and surface temperatures, wind transport, evaporation, and transpiration. It is a fact that 99.8% of the Earth's surface energy comes from the sun [7]. While the solar beam passes through the Earth's atmosphere, it loses 5% of the descending sun's insulation and 15% of it diffused, so the rest of the radiation that approaches the Earth's surface directly equals about 1020 W/m^2 [8]. As mentioned above, the diffusion action resulted from clouds, dust, and air pollutants [9]. So, the atmospheric conditions decrease the quantity of insulation that reaches the Earth's surface and change the color and quality of the incoming light [10].

The solar radiation that reaches the Earth's surface consists of short- and longwave radiation. The shortwave radiation may be absorbed by terrestrial bodies and clouds and reemitted as longwave radiation. This shortwave radiation that approaches the Earth's surface consists of direct, diffuse, or reflected radiation. The direct shortwave beam is the most important component of the three radiation modes. It involves the most part of the incoming energy and the other two radiation modes depend on it, whether directly or indirectly [11].

Direct solar radiation varies with the receiving surface geometry, while the diffuse radiation varies slightly within a small area from slope to slope, and its variations linked to slope gradient [12, 13]. For all the abovementioned, at clear sky, the shortwave solar radiation varies with respect to altitude, elevation, surface slope, and orientation. As a result, the solar energy is distributed unevenly worldwide [14, 15].

As the Earth is one of the sun foci, it revolves around it in an elliptical orbit. It takes the Earth 1 whole year to complete this orbit. The relative position of both the sun and the Earth is represented conveniently as a celestial sphere around the Earth. The line joining the sun and the Earth's center and its projection on the equatorial plane makes an angle called the solar declination angle. This angle equals zero at two times a year that is the venal (20/21 March) and autumnal (22/23 September) positions [16].

To deal with solar energy, there are two primary choices; the first is photovoltaics and the second is solar thermal. Photovoltaic is direct energy conversion where it converts solar energy to electricity. Solar thermal is the usage of solar radiation to supply heat to create a mechanical energy converted to electricity by a thermodynamic system [17]. Reference [5] declares that covering a small part as 0.16% of the lands on Earth with solar conversion systems that have 10% efficiency would provide a power as twice as the world's consumption rate from fossil fuels. For the photovoltaic (our interest in recent study), worldwide installations increased by 7.3 GW in 2009, rising from 6080 MW installed during 2008. While in 1985, the PV installation demand was only 21 MW [18]. PV electric power generation follows daily changing pattern with a peaking at the middle of the day [19]. When an excess electric power is generated, it can be stored in batteries [20, 21].

The PV efficiency varies depending on the thermal properties of the materials used in manufacturing the module. But it also depends on the incident radiant power density. As only a part of the incident solar spectrum is converted into electricity, the rest is converted to heat causing an increase in the module temperature that leads to module efficiency and output power decrement [22]. Many researches made surveys on the outdoor performance of the different types of PV panels at different weather temperatures and solar irradiance. Thongpao measured the output of amorphous and polycrystalline PV panels in variable temperatures and solar irradiances in Thailand. The study recommended the usage of the amorphous thin film for the same location in the hot months of summer because of the polycrystalline efficiency at higher temperature [23].

The climatic condition of the location of the PV arrays has an influence on the solar radiation reaching the Earth's surface [24]. Solar radiation data are available nowadays in most developed country's meteorological stations, but there are many countries suffering from a shortage in these data. One helpful method for collecting solar radiation data is installing a collector [25]. The collector has a benefit that it is affected by the azimuth and tilt angles of the instillation site location. The tilt angle is affected by many factors such as the geographic latitude, utilization period of time, climate condition, etc. [26]. Most methodologies in developed countries based their hourly solar radiation data either on the analysis of recorded data. Some other used modeling techniques depend on meteorological data, like humidity, ambient temperature, wind speed, etc. [27].

The availability of solar radiation data is an important demand for the design of solar systems at a specified location. This data provides information on the magnitude of the sun's energy that strikes a specific surface on the Earth through a specific time period. Due to the difficulty and cost of solar radiation measurements, these data are not always available, and alternative methods to generate it are needed [28]. The costs of the solar system would be reduced when the location site and the solar radiation profiles are matched. Solar radiation varies with seasons and daytime as the sun varies its positions [29]. For a precise and effective solar radiation database, long-term data measurements can be used. These horizontal data have been used to develop efficient mathematical models in Europe to predict solar radiation intensity on tilted surfaces [30, 31]. Solar radiation conversion models were used to obtain data for sites where radiation was not actually measured. This process was effective in resolving this problem [32]. Many models of solar radiation calculation have been developed, and these models have taken into account variables more than astronomical, meteorological and surface effects, and as examples of these models Schaab (2000) work [33]. In the late 1970s, the researcher began modeling solar radiation in Jordan. Al-Salaymeh [34] also completed a computer model of solar radiation in Amman, Jordan, to predict the average daily and monthly global solar radiation on horizontal surfaces. In addition, this program can predict the monthly average of the solar brightness of the city of Amman [34]. Global solar radiation is divided into direct and diffuse beams; the direct radiation is measured using a pyrheliometer. The diffuse radiation is measured by instruments such as pyranometers, solarimeters, or actinography. These devices are installed in multiple places on the area of the location to be measured. Because of the high cost of these devices, it is sometimes difficult to install them in many sites, and these devices have a high degree of uncertainty, which may cause false or incomplete data [35]. Mathematical relationships between the intensity of solar radiation, ambient temperature, relative humidity, and the proportion of solar radiation can be linked to measure the values of solar radiation as data for these mathematical models. These models can then be used to determine the direct and diffuse solar radiation of many sites that do not have proven and measured data by using historical metrological data [36].

At present, softwares have been developed to deal with the quality and quantity of solar radiation measurement data really close to reality. While still using the current radiation measurements devices that operate on older technology, with relatively small basic improvements. Many researches demonstrated several significant problems in these devices' measurement accuracy. References [37, 38] studied the ununiform temperature response of it. The cosine error was investigated by References [39, 40]. References [41, 42] examined the thermal imbalance of pyranometers. Reference [43] explored the effect of wind speed and ambient temperature influence on the pyrheliometer data. But still today, radiometry is still perfected by researchers and meteorologists with the condition of better instrumentation, calibration, and correction techniques to deal with the prementioned objections [44–46]. Reference [3] carried out a review of the current best procedures for reducing the uncertainties of the radiometry by means of calibration and correction.

Gueymard conducted a study to evaluate the impact of instrument uncertainties on the measured data inaccuracies and also to predict instrument uncertainties' effect on short-term and long-term measurement series. The treatise results confirmed previous studies that there are widely underestimates of diffuse and global radiation using pyranometer especially in winter. In addition, the study focused on using appropriate corrective measures to lessen uncertainties. The study discussed other types of measuring problems, as the indirect determination of direct or diffuse irradiance, and the shadow and correction methods. The transposition model sensitivity of the predictions according to inaccuracies in the radiation data is verified [47].

Reference [48] studied global and diffuse solar radiation and solar energy efficiency to offset energy shortages in Pune, Maharashtra, India. Direct and diffuse solar radiation data were measured during the study. Reference [49] declared that as long as direct and diffuse solar radiation depends on local meteorological conditions, the study of solar radiation under local climatic conditions is essential. Solar radiation data can also be estimated using mathematical models in sites with a lack of measured data. Climate variables such as the air mass (AM), ambient temperature, and solar radiation make it difficult to predict the performance and efficiency of photovoltaic units. Standard test conditions (STC) have been developed, which define the maximum PV unit power (Pmax) under specific conditions: 1000 W/m^2, 1.5 AM, and 25 °C module's temperature. These conditions rarely occur at the same time in nature. The performance of photovoltaic units varies with time, which causes variations in temperature and radiation intensity depending on the geographical location [50]. Thirty years ago, Saudi Telecom Company (STC) wanted to develop its own towers to be supplied by electricity generated by photovoltaic modules and asked some photovoltaic specialists to study the requirements. At that time, the researchers suggested that photovoltaic modules must be manufactured with layers that withstand variable weather conditions such as hot sunny, cold, hot cloudy, cold, and moderate [50, 51].

The International Electrotechnical Commission (IEC) proposed a PV rating standard (IEC 61853-1). This standard included characterizing of the PV module performance depending on a matrix of various weather conditions such as HTC, NOCT, LTC, and LIC. Table 5.1 listed these conditions. With this proposed standard, the IEC solicit to enhance the rating method in a way that PV module performance is determined at a set of testing conditions [52, 53].

Buday designed and built a system that has the ability to measure all these parameters, but still the measurement system has a degree of uncertainty in the data it generated [54].

In the literature, he provided a ground to understand the uncertainty level that could be expected. Several sources of uncertainty such as the measurement devices' lack of precision and the fast condition variation like irradiance through measuring periods.

Table 5.1 IEC 61853-1 matrix-based text conditions [54]

Abbreviation	Description	Irradiance (W/m^2)	Module temperature (°C)	Ambient temperature	Wind speed (m/s)
HTC	High temperature conditions	1000	75		
STC	Standard test conditions	1000	25		
NOCT	Nominal operating cell temperature	800		20	1
LTC	Low temperature conditions	500	15		
LIC	Low irradiance conditions	200	25		

Bashir carried out an outdoor study at winter months. The module performance factors were calculated for each module focusing on the effect of solar irradiance and module temperature on these parameters. The module parameters demonstrated high dependence on the solar irradiance and module temperature. The module efficiency and performance ratio showed a decreasing trend with the increase of solar irradiance and PV module back surface temperature [55].

Reference [56] conducted a study on the effects of solar irradiance incidence angle and dirt energy losses in the north of Spain [6]. The tested plant has 400 single vertical-axis trackers and 45° tilted modules. Crops surround the plant with a distance of 1 km from it, and the location was far away from any road with regular traffic flow. The study compared irradiance measured by two horizontal pyranometers and the measurements of irradiance by three calibrated cells located on separate trackers. The effect of dirt was taken into consideration in this study. The daily energy losses were calculated between Feb 2005 and May 2006. The study concluded that in case of tracking surfaces, the PV module losses ranged between 1% and 8%, while for the horizontal surface cases, the losses ranged from 8% to 22%.

Cano conducted a study for two sets of mini-modules; each set has 9 PV modules with varied tilt angles of 0, 5, 10, 15, 20, 23, 30, 33, and 40°. The study focused on the effect of tilt angle on daily and monthly soiling and hence transmitted solar isolation and energy production by PV modules. As the performance of PV cells depends on many operating conditions, some of these parameters interfere with the other studied ones. The resulted data obtained by investigating these two parameters gave the transmitted irradiance at each different tilt angle. Furthermore, the irradiance will estimate the energy loss due to soiling [57].

The performance of the photovoltaic solar module (PV) is affected by the tilt angle and direction of the photovoltaic level. Saleh [58] simulated the effect of tilt angle (azimuth and altitude) on PV performance. The study included many tilt angles (0°, 15°, 30°, 45°, and 60°) in both directions *x* and *y*. The solar radiation values of different tilted surfaces were calculated with different orientations. The study showed that the photovoltaic power generated is significantly affected by azimuth and elevation difference.

Two dependent factors cause the complexity of the representation and study of the performance of PV modules. These two factors are the variation of the solar spectrum with daylight hours, and the second is the change of visual effects with the solar tilt angle. Both parameters are associated with solar radiation, which can be considered the most important parameters of PV outcome. It is therefore very important to measure the radiation at the site to determine the performance of photovoltaic plants. Reference [59] studied the effect of variables such as temperature, solar radiation, series resistance, and diode ideality factor on the performance of two solar modules. Then the authors used a solar test model to measure current values under varying radiated levels.

Mehleri [60] studied several measures to determine the optimal angle of photovoltaic units and how to maximize solar radiation reaching the cell during a specified period. The researchers built a method that included a mathematical model using measured data to reach greater accuracy. The researchers also built a database containing the average global solar radiation per hour on tilted surfaces and various angles of inclination and orientation during the studied periods. The study produced several models linking the angle of inclination and its direction with the average global radiation and its variation on tilted surfaces. The final step involved formulation of the optimal values for tilt angle and orientation.

Emanuele investigated maximizing the global solar radiation subjected to a sloped collecting surface. The study started by calculating the optimum tilt angle for PV panels on two sites, a building structure and a large PV power plant located in typical latitudes in Southern Italy. Diffuse solar irradiance was deemed to specify the PV panel inclinations that maximize dropped solar radiation using the data of global horizontal solar radiation. An algorithm was used to provide a set of tilt angles for every latitude for the simulation [61].

5.3 Solar Radiation in Iraq

Most of the Arab world is located in the global solar belt. Many valuable studies declared that each square meter in the Arab world receives about 640 watts/hour in average. If we estimated that the continuous demand for electricity of the entire Arab world reaches 100 GW, this value can be achieved by installing a PV system with a maximum efficiency of 10% over an area of 1560 km^2. This area represents only 0.011% of the total area of the Arab world (147 million km^2) [62, 63].

Huge number of studies in the Arab world on the PV solar energy applications was conducted especially in Iraq. The potential for PV solar energy applications in Iraq is enormous. Figures 5.1 and 5.2 show the monthly average of the daily sunshine duration in hours for January and June in Arab countries. Iraq as mentioned has an average daily sunshine about 7–8 h in winter increased for 11–12 h at summer days. These sunshine hours are very promising for the utilization of solar energy, either for thermal or photovoltaic application. The application of PV systems must take into account the provincial conditions, as the available resources, and the demand degree. Iraq has a benefit of the high solar radiation intensity. Also, it is a wealthy country with large economical abilities. If the shortage in electricity demand is added to the last two factors, the formula of PV system application success is completed.

Al-Hilphy conducted a practical and theoretical study investigating the value of the incident solar radiation intensity on two surfaces at Basra province, Iraq. The first one is a horizontal surface, and the second one is making an angle of 30^o with the horizontal. The results of the study showed that the intensity of solar radiation increases with daylight hours to reach a maximum of 740 W/m^2 in the middle of the day. The study also showed that the solar radiation falling on the slanted surface has higher solar density than the horizontal surface. The study found a large difference in the intensity of solar radiation measured between the years 2006 and 2011 [65].

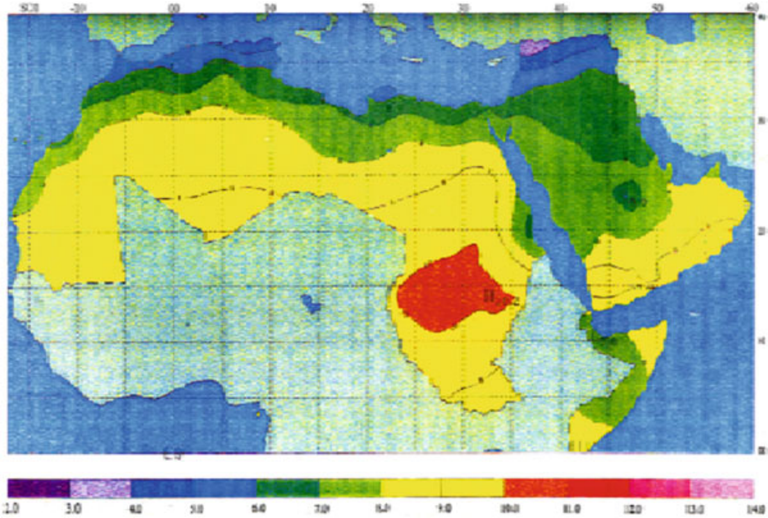

Fig. 5.1 The monthly average of the daily sunshine duration in hours for January in Arab countries [64]

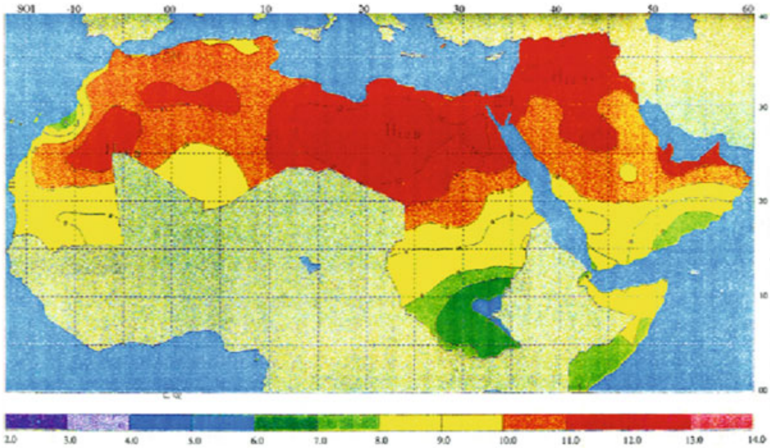

Fig. 5.2 The monthly average of the daily sunshine duration in hours for June in Arab countries [64]

Sharif [66] clarified and confirmed the idea of building the second proposed project of photovoltaic systems and wind parks similar to that proposed for the African Sahara desert. The study demonstrates the efforts of Iraqi scientists and experts in the field of renewable energies and gas and oil industry to interfere with DESERTEC network. They proposed a second project to be built in Iraqi western desert. The general idea is to utilize solar power during daytime with the assistance of natural gas during nighttime [67]. The generated electricity is thought to be exported to Europe through Turkey. The proposed power value is to exceed more than 6000 MW. The study of project costs and KWh cost calculations has shown that the proposed project is feasible.

The most attractive issues of this project are:

1. The location of the proposed area lies in the high-intensity region of solar energy.
2. The proposed location is geographically connected with Europe through Jordan, Syria, and Turkey.
3. The proposed location is available land and suitable for the foundations of large power plant with the future extension abilities.
4. The proposed location lies near a huge reserve of natural gas that can be used to support the solar plant power production at night or cloudy and rainy days.
5. The proposed location lies near a sufficient and available water in the region. This water can be used for cleaning the dust off panels and for turbine coolant.
6. There is a demand of large amounts of electric energy at recent time in Iraq. In the same time, Turkey and European countries are thinking of gathering the production of thermal energy in parallel to the production of renewable energies [68].

Abbas studied the monthly and seasonal variations of cloudiness for variable zones of Iraq. Cloudiness differences were found very low all over the country and descend for the south areas. In the summer, the clouds were found to be higher in the south than in the north. The study found that the pyrheliometric conditions for Baghdad can be taken as a representative of all Iraq. At clear days, the study took into consideration the incoming solar radiation within all months of the year, and the horizontal radiation at Baghdad and applying empirical formulas. The study could estimate the amount of solar radiation received at any graphical location in Iraq, at any time of the year, by the knowledge of the cloudiness or the percentage of possible hours of sunshine [69].

Omer investigated the cyclicity in the recorded climate to resolve some complexities in the atmospheric system. The study took into consideration the periodicities in the sun spot number, the time series, and the annual and seasonal temperature time series. The researchers were able to study the data stored and distributed over a period of 63 years for the period from 1948 to 2011. They found that there were several periods where the annual and seasonal temperature changed for the bundle of 10.5–12.5 years related to the solar cycle. Also, the Kurdistan-Iraq (north Iraq) temperature is negatively correlated to the solar cycle [70].

Alasady in his paper focused on the sufferance of Iraq due to the scarcity of electrical power since the nineties till present time. Also, the long hours of the electricity cutting forced the Iraqis to use the available alternatives such as generators (with high KVA or small wattage). The estimated number of these generators is about four million generators and maybe more. This condition forms an additional economic pressure and a continuous damage to Iraq's environment due to the combustion-emitted pollutants increasing [71]. Iraq received solar radiation averaging about 6.5–7 kWh/ m^2 with periods of sunshine exceeding 3300 h per year. These numbers ensure access to large amounts of energy if it is compared with, for example, Canada and Russia. The sunshine period in these two countries not exceed

1000 h a year, but it is used to generate solar energy. The study is counted a part of projects of the Center for Energy Research and the Environment for the period from 1981 to 2006. These projects included the heating, cooling, and lightening of the building of the energy research center which is 6361 sq m. using solar energy to heat, cool, and lighten the home solar Iraq which is a guest house with a total area of 600 square meters. A nursery building consists of 120 children bed heating, cooling, and electric power generation, using solar energy. In addition to the use of solar water pumping in Rabia, Samarra and Fudhaliyah [72].

5.4 Temperature Effect on PV

The standard system adopted to measure the standard PV performance relays on testing the PV module under standard test conditions (STC), and these conditions consist of 1000 W/m^2, 1.5 km (air mass), and the unit temperature of 25 °C. Another test, called nominal cell temperature, is also used. The standard test conditions are 0.8 kW/m^2 of solar radiation, 20 °C of ambient temperature, and 1 m/s of wind speed [73].

PV performance was affected significantly by environmental factors as solar irradiance, temperature, air mass, and wind velocity [54]. Also, the PV modules' electrical efficiency ranged between 6% and 18%. However, it is very difficult to achieve the occurrence of these conditions simultaneously in nature. So, the performance of PV modules varies primarily because of differences in temperature and the air mass (AM) that resulted from geographic location and time variation [74]. As a result, it has become difficult to predict the performance of photovoltaic (PV) units, which explains why nonlinear performance characteristics of various solar cell technologies are produced [52]. Studies have shown that increasing the temperature of photovoltaic cells by 1 K results in lower electrical efficiency of existing crystalline silicon cells by about 0.4–0.5% [75, 76].

Irradiance affects PV power significantly. Whereof many researchers investigated its effects and the influence of other factors related to it as the angle of incidence and cell tilt angle [77, 78]. As long as solar cell depends on solar radiation to produce electricity, so the higher the solar irradiation, the higher PV performance resulted. Unfortunately, this concept is simple and far away from reality. PV produce electricity in the practical life about 15% of the irradiance, that means 85% transforms to heat in the cell body. The heat absorbed by PV panel increases its temperature. The temperature of active PV cells can be considered to play a major role in the photovoltaic process, because the high temperature causes a decrease in both the output voltage and the output power of the cells and the performance of the PV modules decreases significantly with the increase in temperature [79]. The physical properties of solar cell materials are affected by operating temperatures, as well as by surrounding environmental and climatic conditions that have the same effects [80].

A great number of papers have illustrated a significant reduction in the efficiency of various PV technologies under high-temperature operation.

Iraq passes about six hot months per year, and the peak is at July and August. The irradiance is high at these months as well as air temperature. In Iraq neighborhood countries, many studies have been conducted to test the temperature effect on PV power. Charabi [81] studied the geographic and metallurgical variable of the Sultanate of Oman. It was selected due to its location in the core of the Sun Belt, with high potential of solar radiation. Oman is characterized by hot temperature and vexing arid climate [82, 83]. He studied the land suitable for large PV station constructions. The study results manifest that only 9% of the total area of Oman is highly suitable for large PV power plant because of high solar irradiance and dust escalation. The different PV technologies tested showed that the CPV technology provides high technical potential for implementing large solar plants.

Hughes [84] worked on a computational fluid dynamics (CFD) model for heat transfer during the operation period of a PV panel and used this model to determine the rate of heat dissipation. The study was conducted on the conditions of the United Arab Emirates climate and specifically the conditions of Dubai City. The study suggested the arrangement of fin-heat tubes and analysis to minimize the effect of high temperatures. The study concluded the usefulness of the proposed method of using the fin-heat tube and its efficiency for practical use in high-temperature areas. The temperature of the PV panel has been exceeded by 70 °C during practical experiments. The researchers have used the proposed fin-heat tubes to remove heat by natural convection. The CFD analyses conducted by the researchers identified the optimum refrigerant temperature that could be reached under the UAE's environmental conditions at 30 °C, a temperature within the range of solar cells.

Makridas [85] studied an impact temperature panel on the performance of a system for stabilizing in Cyprus. The evaluation period lasted more than 4 years during which heat losses were calculated for several PV systems. The researchers used plant temperature coefficients and temperature coefficients assessed using external technology. The study showed that the highest thermal losses on the annual return of energy suffer from the single and multi-Crestline Technology. While thermal losses for thin film technologies are lower than other techniques. The study concluded that the use of thermodynamics has an important effect on the seasonal behavior of photovoltaic arrays.

Iraq can be considered at the second level of the countries that are exposed to the highest solar radiation after the core of the solar belt states. The potential of Iraq to establish solar facilities, whether physical or human, is highly available. The average annual energy received per day from the sun ranges between 4.5 and 5.4 kW/m^2 in Iraq [86]. Al-Halphy [87] studied theoretically and practically the intensity of solar radiation on a horizontal surface and another fixed at an angle of 30° from the horizontal in Basra city, southern Iraq. The study lasted from 2006 to 2011. The results of the study showed that the maximum solar density that reached 740 W/m^2 occurred in mid-August. The study indicated that there is a very significant metallurgical phenomenon. The study determined that there is a large difference in the intensity of solar radiation between 2006 and 2011, as solar intensity in 2011 was higher than in 2006 [88]. Chaichan clarified that Iraq has about 3600 hours of solar brightness per year and a minimum of about 3000 of sunny hours a year. The solar intensity per hour in the Baghdad City Station ranges from 416 W/m^2 in January to 833 W/m^2 in June [89].

Many theoretical and simulation papers worked on modeling the temperature of PV modules. These papers succeeded in obtaining correlations to predict the cell or module temperature based on the incoming solar irradiance, ambient temperature, and wind speed [90–94]. These studies suggested that the module temperature subjected to immediate changes, so the thermal mass of the modules was not considered. Other studies extrapolate a known reference condition (like the normal operating cell temperature) to predict the module temperature [95]. The assumption that module temperature is uniform across the array does not appear acceptable. Farr [96] formed a comparison of two identical PV systems in different climates. The results indicated that module temperatures varied by several degrees across the array.

In all the previously mentioned articles, the steady-state conditions were valid. In fact, a steady-state model is not able to predict the PV cell or module temperature fluctuations during periods of rapid irradiance oscillation. The changes in irradiance can take place within seconds as field measurements indicated. Jones [97] point out to the slow thermal response of the PV module to sudden changes in irradiance. This slow response indicates the effect of the thermal mass on the thermal response. Tsai [98] indicated that the rapid irradiance changes appear as a variation within 3 °C of the measured module temperature, but a real temperature fluctuation is over 20 °C. This error of this high value in the thermal model will result in major errors in the predicted output power.

Lobera [99] studied theoretically and practically the thermal response to changes in irradiance and wind speed for PV modules. He proposed a dynamic state thermal model of PV modules, depending on the thermal mass of the module. All apropos climatic conditions and heat transfer mechanisms were taken into consideration. The proposed model was based on the non-steady-state equation depending on 3-day measurement periods on winter, spring, and summer time. The results indicated accuracy less than 2 °C for 80% of the time.

The obstacle of high weather temperature and its effects on the PV power reduction, gave excuses for Iraq decision makers to neglect it. In spite of all its known advantages, till now PV modules entered Iraq in abashment. As long as the produced electricity and the efficiency of PV module can be improved by cooling the solar cells itself with a stream of air or water. This led to the developing of PVT hybrid solar technology. PVT collector is a module that produces electricity and, also, serves as a thermal absorber. The results are simultaneous production of both heat and power, as both solar heat and solar electricity demands are supplementary. PV cells utilize a part of the incident solar radiation to produce electricity, while the other part recovers part of the waste heat and uses it for practical applications. Four categories of PVT till now are researched, namely air-based PVT, water-based PVT, refrigerant-based PVT, and heat pipe-based PVT [100].

Teo [101] used a parallel array of ducts on the back of the PV panel designed to distribute airflow uniformly. After conducting the tests with and without active cooling, a linear relationship was found between efficiency and temperature. The electrical efficiency dropped with about 8.6% without cooling, whereas PV operating temperature was reaching 68 °C. The cell temperature could be sustained at 38 °C by employing a blower, and the efficiency could be kept at around 12.5%. Sarhaddi [102] investigated analytically a model of the performance of a solar photovoltaic thermal (PV/T) air collector. Corrections were done on heat loss coefficients to improve the used thermal model. An agreement was achieved between the results of numerical simulation and the outdoor test results of [103]. Charalambous [104] mentioned an easy comparison between the design variables that could affect the thermal and electrical performance by reviewing all standard types of PV/T collectors.

The second category PV/T water collector is more popular than the other types of PV/T categories. Its popularity comes from the diversity of the water collector PV/T system applications and properties [105]. Krauter [106] investigated the effectiveness of the utilization of a nozzle of injected water on surface to cool PV cells; the nozzles were located at the top of the module. The injected water reduced the reflection by 2–3.6%, in addition to help keeping the surface clean. The injected water reduced the cell temperatures up to 22 °C, which resulted in a gain of 8–9% in the electrical yield. PV cooling by using percolating water on the upper surface of the call was studied by [107]. A significant decrease of about 26 °C in cell operating temperature was achieved, while the measured surface temperature in a typical summer day was around 58 °C. The system output was increased by a range of 4–10% with this cooling procedure. Fifty percent of output increase was revered to direct contact cooling between water and PV module surface. The remaining part revered to refraction of the solar radiation in water film.

The removal of excess heat from both cell surfaces by immersing the cells in a dielectric liquid was proposed by [108]. Dimethyl silicone oil was used as the dielectric fluid, and a long-arc xenon lamp was employed as the illumination source. A total uniform temperature distribution was achieved, with an uncertainty degree of less than 3 °C between the simulation and experimental data. Yang [109] reported that the module temperature can be decreased with about 20 °C. They used functionally graded material (FGM)-based water tubes to achieve this effective reduction in the panel temperature. Kerzmann [110] presented a simulated study of linear concentrating PV systems. The system used an active fluid cooling channel which was made of high-efficiency multi-junction cells. The surplus heat was removed by means of the active channel cooling system. Higher cell efficiencies were achieved, and the withdrawn heat from the module was stored and used for heating purposes in domestic use.

Chandrasekar [111] developed a simple PV cooling system by using cotton wick structures. The moist cotton wick structure was placed facing the ground on the back surface of the module. The expected cooling effect of PV module was attributed to the capillary action of the cotton wick. This novel procedure reduced the cell temperature from 65 to 45 °C. This passive cooling system utilized cotton wick, and water was compared with the utilization of Al_2O_3/water and CuO/water nanofluids. Reductions of about 11% and 17% in cell temperature were achieved with nanofluids compared to about 30% reduction with water. This difference was referred to the adherence of nanoparticles to the wick fibers which hampered the capillary wick action.

Kearn [112] studied the use of heat pump systems to cool up the PV modules; this procedure wasn't previously studied. The proposed system consisted of simple PV/T collectors connected to heat pump systems. The energy savings and economic benefits were studied. The proposed new concept of the PV/T unit is accompanied by a heat pump application. Evaporating coils have direct expansion under photovoltaic modules, allowing for evaporation of refrigerants when passing through the units. Coils act as the evaporation section of the heat pumps. This design allows for evaporative cooling at a very low temperature of about 0–20°C, resulting in photovoltaic cells being cooled to a low temperature. The study found a significant increase in the electrical efficiency of the cell. The thermal pump compressor increases the resulting steam pressure and reaches the condenser to provide heating. The compressor can be driven by photovoltaic power generation, thus creating a solar-powered solar pump independent of fossil energy [113]. PV/T collectors cooled by heat pipes are still relatively new technology so researches in this field are very limited. A flat plate with swivel heat tubes for photoelectric cooling was studied. The results of the study concluded that heat pipes can overcome problems in the refrigerant-based system. These include the possibility of leakage of refrigerants, the distribution of unbalanced cooling flow, and the difficulty in maintaining pressure or pressure in the parts of the system [114]. Combining thermal conductivity and phase transition principles resulted in efficient heat transfer mechanisms of heat pipes. Heat pipe consists of evaporator section, adiabatic section, and condenser section. It provides a solution for removing and transmitting heat [115]. Zhao [116] studied PV/heat pipe combination by proposing a PV/flat-plate heat pipes array. The target was to cogenerate electricity and hot air/water together. The resulted PV efficiency increased by 15–30% compared to the sole PVs. Also, the overall solar conversion efficiency of the module was around 40%. Feng [117] investigated a new concept integrating PV/T system using oscillating heat pipe. The system elements consisted of oscillating heat pipes, headers, finned tube, graphite conductive layer, metal frame, PV laminate module, and insulations. The coolant in the metal heat pipes absorbed heat from the operated PV cells and change its phase to vapor. The vapor condensed after passing through the finned tube releasing its heat to the surrounding fluid and reverts to the absorber by effect of capillary forces and gravity.

Iraq can be considered as one of the best places for utilization of solar power due to the abundant sunshine and flat open land near population centers. Unfortunately, solar specifications and geographic characters are only one factor of Iraq's success in solar power opportunity. The impact of two decades of war and 15 years of economical block resulted in years of underinvestment in the power sector. In addition, rapid increases in demand for electricity create significant differences between demand for energy and production. This situation did not prevent the investigation in solar energy sector to evaluate the best solution for introducing solar energy to public.

Amauri [118] used two selected sites in Iraq to analyze the electrical and thermal performance of the PV/T hybrid system using mathematical modeling. The proposed model was used to study the performance of the system for a winter day and on a summer day in the cities of Baghdad and Fallujah, 50 km to the west of Baghdad. The study focused on several variables such as cell temperature, ambient air temperature, thermal gain, photovoltaic current, and voltage. The study identified the effects of temperature in the sky, air, and cell input, air flow rate, and solar radiation on the performance of the PV collector. The results showed that the total electrical, thermal, and overall efficiencies of the two systems used in the study were 12.3%, 19.4%, and 53.6%, respectively, for the winter day, while the summer day were 9%, 22.8%, and 47.8%. The study concluded that photovoltaic/thermal systems would be able to operate with acceptable efficiency in Iraq.

References [119, 120] studied several aspects of the PV/T systems to ensure their eligibility for future work in the production of electric power. The papers explained the techniques used in system configuration. The researchers reviewed the thermal and electrical systems of the PV/T systems and their various applications. The articles presented a comparison to the efficiency and performance of the PV/T systems depending on the coolant used, such as air/air, air/water, water/water, and finally water/nanofluids. The use of nanoparticles and water as a coolant fluid improves overall system efficiency. The two studies concluded that further research is necessary to improve the efficiency of these systems, reduce their cost, and improve their technical designs.

Reference [121] study showed that the addition of 3% of nano-SiC to water as a weight ratio resulted in increasing the density of the nanofluid and increasing its viscosity and improved its thermal conductivity clearly. Experiments have shown that the tested fluid has good stability and can be used for a long period. The use of SiC nanofluid caused an increase in the electrical efficiency by 24.1% more than the photovoltaic panel alone, while the thermal efficiency increased by 100.19% compared to the state of water use for cooling.

Reference [122] checked the possibility of using three nanomaterials when added to water to form cooling fluids for the use in PV/T systems. The researchers used several volumetric fractions to determine the best concentration of nanoparticles. The study showed that the use of any nanofluid gives better thermal conductivity with very limited increase in viscosity and density of the resulting fluid compared to water. The study tested several nano materials as nano-Al_2O_3, nano-CuO, and nano-SiC. The results showed that nano-SiC water has the best thermal conductivity compared with other nanomaterials. Also, its stability last longer than the other tested nanofluids. It is also observed that copper oxide nanofluid has a higher thermal conductivity than nano-alumina, but its stability is lower.

Al-Waeli et al. [123] studied the use of phase change material (PCM) with cooling nanofluid system to control the thermal capacitance of the system. This new system was proposed to gain higher electrical efficiency, increasing overall efficiency of the PV/T system. Nano-SiC particles were added to the paraffin wax and in the cooling fluid to enhance the thermal conductivity of both paraffin and cooling fluid. Field-based tests have been conducted in Malaysia. The proposed system use caused a decrease in cell temperature up to 30 °C during the peak solar radiation period (12:30 AM to 1:30 PM), resulting in improved PV/T system performance. Besides, the thermal efficiency of the proposed system increased up to 72%.

5.5 Humidity Effect on PV

PV modules are affected by water seriously. Also, water causes hydrolysis of polymeric components that result in the degradation of the module efficiency. Water causes corrosion of the glass and the metallic grids and interconnectors [124]. Basically water contained in air as moisture defined as the ratio between actual water vapor pressure in the air and the saturated water vapor pressure at the same temperature [125]. This moisture diffuses into photovoltaic (PV) cell through cracks or the breathable back sheets [126]. Moisture quantity is measured by air relative humidity (RH) which varies at the front encapsulate with that of a backside encapsulate [127]. The dependence on water vapor saturation pressure in measuring RH and its considerable relation with temperature cause these differences [123]. When PV modules are operated at hot and humid climates, the moisture content in the air causes degradation to the module performance [128]. The changes depend on moisture diffusion process through PV module which is a slow process [129]. When moisture penetrates the polymer and reaches the solar cell, it weakens the interfacial adhesive bonds, causing many effects [130]. Some examples of these effects are the PV delamination [81], increased numbers of entry pathways, and erosion of welded joints [131, 132].

Therefore, many researchers have studied the effect of relative humidity on PV modules. Bhattacharya [133] investigated the impact of natural outdoor conditions in Rajasthan like high ambient temperature, dust, humidity, and scarcity of rain on PV modules. The researcher clarified that the Rajasthan average relative humidity (RH) is about 42%, with maximum achieved RH of 70% at August and minimum of 25% during the month of March. The study clarified that corrosion is the primary effect of humidity especially if both humidity and high temperature meet together. The atmosphere conditions of high temperature (higher than 40 °C) and humidity (less than 60%) cause a long-term deterioration. While higher levels of temperatures and relative humidity will accelerate the corrosion process, other yields like the growth of fungi increase at the high relative humidity levels between 75% and 95%. Moisture forms a sticky surface that catches dust and dirt particles on the PV surface. Laronde [134] and Peike [135] tested the degradation of PV modules due to corrosion. They concluded that the main cause of PV module degradation is the grid corrosion that causes the conductivity reduction between the emitter and grid. Their studies declare that moisture penetration increased with increasing temperature, as well as adhesion strength reduction. Touati [136] investigated the effects of temperature, dust, and relative humidity on PV system efficiency. The monocrystalline and amorphous solar photovoltaics were used in Qatar environment. The results showed that dust accumulation affects PV performance higher than ambient temperature and the relative humidity. Also, increasing temperatures above 40 °C has great influence on amorphous PVs.

Mekhilef [137] measured degradation in solar cell efficiency caused by humidity. The study mentioned that increasing wind velocity will lower the atmospheric air relative humidity causing a better efficiency. On the other hand, high wind movements may lift dust and scatters it in the PV surroundings causing lower cell performance. The study concluded that dust, humidity, and air velocity affect together the performance of PV cells. The exchanging influences of these factors must be studied together to evaluate PV cell efficiency. Gwandu [138] demonstrated that the humidity has influences on the sunlight irradiance level, where it will be radiations subjected to refraction, reflection, or diffraction caused by water vapor particles. These cases reduce the received solar radiation level causing nonlinearly irradiance alterations. A little nonlinear variation in open circuit voltage is accompanied with large linear variations in short circuit current.

Kempe [126] clarified that air humidity is likely to cause cell failure if the moisture permeates the crystalline silicon cell through cracks in the cell. The solar cell is subjected to cell brittleness by the moisture corrosive effect, which is very influential in the degradation of photovoltaic cells. The change in the color of the photovoltaic units can be seen as evidence of panel failure and reduced service life. Moisture degradation in photovoltaic modules made of crystalline silicon causes an electrical bind failure to the cell most of the time. The films are also thin, and moisture-sensitive units corrode. Therefore, each of these processes causes further deterioration of cell performance caused by hot and humid weather.

Prakash [139] illustrated that the PV module efficiency is low and is influenced by many environmental factors as dust, temperature, wind velocity, and relative humidity. The researchers considered the PV cell as a glass cell and took glass physical properties as a reference. They cooled the PV cell using a non-pressurized cooling system to deliver a least amount of water once in a while. The study results indicated that in hot and dusty areas, the cooling and cleaning of the PV panels is possible by using water cooling system. However the cooling process must start after the cell temperature reached 42 °C. Of course, the researchers neglected the cooling water corrosion effects on the long range.

Darwish [140] clarified the relation between humidity and irradiance and their effect on short circuit current by the equation:

$$\eta = \frac{I_{\mathrm{SC-max}} \cdot V_{\mathrm{OC-max}}}{A_{\mathrm{C(irradiance\text{-}level)}}} \tag{5.1}$$

where A_C is the effective area of the module, I_{SC} is the short circuit current, V_{OC} is the open circuit voltage, and η is the conversion efficiency. The study concluded that the wind speed affects the received irradiance in a reverse of relative humidity effect. On the other hand, the PV modules long-time exposure to humidity may lead to water ingresses into the PV panel causing cell performance reduction.

Omobo [141] studied the effect of relative humidity on the efficiency and effectiveness of converting solar energy into electricity for PV modules. The results showed that there is a proportional relationship between solar radiation, output current, and solar cell efficiency. Relative humidity in the air affects the intensity of solar radiation, and as a result, they both have a negative impact on the output voltage of photovoltaic cells. The researchers were able to maximize PV power with operating conditions at 43°C and relative humidity of 77%. Kattkar [142] has analyzed the effect of photovoltaic cell temperature and moisture effects on the performance of solar cells to assess the efficiency of photovoltaic cells produced in different weather conditions. The results showed that the environmental conditions in which photovoltaic cells work have a direct impact on energy conversion efficiency. The study was conducted in severe atmospheric conditions with an ambient temperature of 58°C and relative humidity of 60%. These extreme conditions have reduced the efficiency of photovoltaic cells by 32.42%.

Kazem [143] studied the effect of relative humidity on the performance of three types of photovoltaic cells (PV) in the climate of Oman, which is characterized by very high relative humidity. The results of the study showed that the performance of solar cells is enhanced in conditions of low relative humidity as well as the voltage and increased the electrical power produced. Besides, when relative humidity decreased, the monochromatic panels have higher efficiency than crystalline and amorphous silicon technologies. Al-Hanai [144] analyzed the effects of the various variables affecting the thin film Si and the performance of the PV units. The study area was the United Arab Emirates, characterized by dry and cold weather conditions at winter and hot and humid at summer. The study showed the apparent effect of air humidity on the performance of the photovoltaic cell. The researchers concluded that moisture is linked to an inverse relation to the temperature, which makes the assessment of its real effect in the performance of the cell complex. Finally, a significant reduction in overall setup performance was observed as the power produced in the grid was fed through the inverter.

Ettah [145] investigated the effect of relative humidity on the solar panel performance in Calabar, Nigeria. The study concluded that at low relative humidity between 69% and 75%, the output current from solar panels increase. At relative humidity values between 70% and 75%, the voltage output increased, as well as it increased with relative humidity reduction. The results clarify that solar panel efficiency is high during low relative humidity period. Therefore, Ref. [95] found that low relative humidity improves the solar panel performance.

Klampaftis [146] investigated the effect of humidity on undiffused passivate silicon oxide. The study found that *n*-type silicon wafers have high resistivity to 100% relative humidity at 75 °C for variable time periods. When PV panel was exposed to humidity, a significant increase in surface recombination was observed. The researchers suggested three mechanisms that may cause the degradation: first, the diffusion of moisture through the SiO_2 and its reaction with hydrogen molecules at the Si–SiO_2 interface; secondly, a reaction of water vapor with the SiO_2 creating silica acid molecules, which alters the film stress, thereby increasing the density of states at the Si–SiO_2 interface; and thirdly, the surface charge sedimentation during exposure to sun radiation. Panjwani [147] tested the effect of humidity ranges between 40 and 78%. The results indicated that there is an approximate loss of about 15–30% of the PV power. Humidity is found to bring down the utilization of solar energy about 55–60% from just 70% of utilized energy. This results from a minimum layer of water vapor in the solar cells facing the direct sun, as solar radiation hits the face of solar cells will suffer from loss of energy absorption by the cell because of its reflection.

Omubo [148] clarified that for PV modules located far away from the seashore with a lower relative humidity proceeds higher efficiency, as at low relative humidity between 65% and 73%, the output power achieved was the highest. Low relative humidity results in increasing the solar flux; consequently, the output current and efficiency of the solar panel are improved. Rachman [149] investigated the impact of outside conditions and of the efficiency for solar-assisted desiccant cooling system. One of the study findings was that the increase in inlet air humidity results in increase of moisture removal. Better system performance can be achieved at lower inlet temperature and humidity ratio of regeneration air.

Chegaar [150] measured the effect of solar radiation on three types of solar cells in Algiers. The results showed that efficiency increased with increasing air mass of monocrystalline and multicrystalline solar cells. The results were reversible to the amorphous silicon solar cells under the same conditions. The study concluded that efficiency increases with increasing relative humidity of the three solar cells tested. Ndiaye [151] reviewed various studies of methods that caused the deterioration of photovoltaic module. The study examined the effect of corrosion, discoloration, delamination, and fracture of key modes of photovoltaic units of deviation defined in etiquette. The researchers concluded that corrosion and discoloration are the dominant factors in photovoltaic cell degradation, although the modeling of different degradation types is still poorly studied in literature.

Kemp [152] explained that humidity causes corrosion if it enters the PV module through the edges of a laminate. Corrosion metal attacks and PV cell connections increase leak currents causing loss of performance. The results showed a relationship between the humidity inside the PV module and the degradation rate. The study focused on moist and wet geographical areas such as Miami, Florida, and the United States. The study said that the only way to prevent moisture penetration is to seal it using low-spreading fillings containing a large amount of dried material. Wohlgemuth [153] conducted an accelerated test called 85/85 ($T = 85$ °C/ RH = 85%) in accordance with IC 61215 [153]. The results showed that corrosion occurred after 1000 h of the PV module exposure to climate under 85 °C and 85% relative humidity. Other researchers [154, 155] investigated the impact of corrosion and discoloration as prevailing patterns of photovoltaic degradation units.

Delamination is a condition in which the loss of adhesion appears between the cells and the windshield or between polymer encapsulation and cells. This phenomenon causes the reflection of light to increase and the moisture penetration of the unit structure [156, 157]. Skoczek [158] studied the impact of pollution on the deterioration of photovoltaic units. When lamination occurs on the edges of the unit, it becomes very hard. In addition, it raises the risk of electrical hazards to the photovoltaic cell. Pollution is more common in hot and humid climates. Moisture permeation in the solar cell most often causes various chemical and physical damages to the metal and cell connections. This penetration also causes the accumulation of salt in the photovoltaic unit and the occurrence of contamination. The hydrofluoric acid formed by the fluorine and tin oxide contained in the PV unit has drilled the interconnection of the cell [159]. Discoloration is the change in the PV cell material color which turns to yellow and sometimes brown. Discoloration occurrence causes an adhesive material between the glass and the PV cells that result in a degradation of the encapsulate module. The light transmittance reaching the PV cells is reduced due to discoloration, and as a result, the output power of the module is reduced [160]. Oreski [161] clarified that the main causes of PV cell degradation are the meeting of ultraviolet (UV) rays and water with temperatures higher than 50 °C. Discoloration may occur in various and not neighboring areas of a PV cell depending on the different characteristics of the used polymers. Discoloration may come from the encapsulating polymer.

Kojima [162] studied that the yellowing afflicts the solar cell. The researchers exposed PV modules to artificial radiation. The study concluded that a rapid PV cell degradation occurs with the photosensitivity increment after the exposure for more than 400 h. In addition, the occurrence of a weak yellowing on the cell increased the degradation [163]. It was recorded that the encapsulate discoloration appears when UV irradiation reached 15 kWh/m^2, with a wavelength ranged between 280 and 385 nm [164]. A long-term slow module degradation and the time of exposure of PV modules to UV radiation are correlated linearly [165].

Glass breakage occurs during installation and maintenance in most of the cases. Also, it happens during the transportation of cells to their installation locations [166]. The broken or cracked cell may keep operating correctly for a long period of time, but the electrical shock hazards due to moisture infiltration increases. Cracks and breakages in cells cause corrosion, discoloration, and delamination. It is very difficult to detect cracks on the newly installed PV module with the naked eye, but it can be perfumed by employing optical methods [167]. In recent years, producers tend to vary the cells' service thickness in order to save it and to reduce the costs of PV cell manufacturing. However, this thickness reduction increases cells' fragility and susceptibility to breakage during handling [168].

The highest relative humidity in Iraq (as shown in Table 2.7) is 78% in Mosul, central Iraq (in January). RH minimum value in Iraq is about 16.2% at Al Najaf at middle of Iraq (in July). The RH values listed in Table 2.7 manifest the possibility of utilization of PV modules efficiently in Iraqi environments.

5.6 Wind Effect on PV

The sun's energy is abundant and reasonable choice for a clean energy source that provides secure power supply for the future development and growth. There is an enormous advance in the understanding of the operational principle of photovoltaic arrays that led to a fast increase in the power transformation efficiencies of these devices. Solar cells exposed to ambient conditions affect its performance and output. The temperature changes affect the power output of the cell as well as the environmental dust accumulation on the cell surface. The desired efficiency of PV cell depends mainly on the ambient temperature around the PV module [169]. Solar cells operate better in certain weather conditions, but, since these conditions are always varying, the solar PV arrays do not work under standard operating conditions. The

PV system's performance does not depend on its basic characteristics only, but it depends also on the environmental conditions. As an example, the ambient temperature plays an important role in the PV module performance [170].

The solar PV cells are manufactured at STC, but they are used for domestic purposes in areas exposed to the environmental conditions like ambient temperature as well as wind speed. So, the wind speed affects the performance of the PV arrays also. Sun is responsible indirectly on the wind energy and its impact on PV cell performance. Wind energy is used globally as a successful alternative technology for generating electrical energy [171].

As PV modules are exposed to environment, then they are exposed to wind all the time. Wind has multivariable types of effects on the PV cells. Firstly, a positive impact, which is increasing the natural and forced convection cooling of the PV panel. Cooling the PV cell helps in maintaining its performance as high as possible. Secondly, the wind negative influence can be divided into two categories: (1) the force exertion on the PV panel that can lead to a significant structural detriment and (2) the sand and dust irritation in the air that settles and accumulates on the PV surface after the wind's sensation [172].

The nature of the wind's force induced on the PV array's structure depends mainly on the wind direction, speed, shape of the structure, and exposure conditions [173]. The PV modules were set in two places, the ground and on the roof of the building. Ground PV units are at low altitude, submerged at the lowest point of the air boundary layer, and wind velocity cannot be predicted due to symptoms and severe disturbance [174]. The average wind speed in the least affected area is affected by the roughness of the Earth. The roughness cannot be determined precisely because of the variation in the size of the terrain that causes this roughness, including size, shape, density, and distribution (e.g., trees, buildings, etc.) [175]. Common PV modules are rectangular-shaped flat plates. Both ground-mounted PV modules and flat rooftop mounts are commonly inclined to extract the optimal energy. The PV module's inclination angle is determined by the latitude of the location. The arrays are installed to donate the best angle for capturing the maximum amount of sunlight [176].

The manufacturers perform a complete series of qualification tests on random samples of modules to confirm that the product matches the long-term performance expectations, before presenting it for sale. The American Society for Testing and Materials (ASTM) developed the qualification tests and standards by the Institute of Electrical and Electronics Engineers (IEEE). These tests include a variety of mechanical, thermal, and electrical qualification tests [177].

Wind load's impact on solar PV arrays has been extensively studied [178]. Wind forces vary dramatically depending on the location landscape and the solar array's shape and height. Reference [179] demonstrated that higher wind loading affects isolated arrays experienced than that mounted in clusters. Also, the arrays in the first row facing the wind shielded significantly the subsequent module rows from the majority of the wind force. The study concluded that the modules at the boundaries of the array are subjected to the highest wind loads. Reference [180] showed that the flowing wind parallel to rows of modules produced insignificant loading conditions.

For the panels that face the south tilted toward the sun as in north quarter, the northern wind may cause a significant uplift on the back row of the modules. The southern wind will strike the face of the first row of PV panels. The aerodynamic wind testing conducted by Ref. [181] revealed that large spacing between module clusters may lead to channel flows between modules that result in higher wind loads on internal module rows.

A dynamic mechanical loading tryout is conducted to simulate wind loading that needs a 30 psi load distributed uniformly to be applied to both the front and back surfaces of the PV panel for 10,000 cycles at a rate less than 20 cycles per minute. This test has an advantage of executing a tryout that can quickly simulate environmental conditions to obtain the reliability of the mechanical design. This test cannot fully simulate real-life conditions, since wind storms from any angle and it does not necessarily cross the surface uniformly or normally to the front or back faces, and this is the disadvantage of this test. The tilt angle and magnitude of a PV array varies depending on the location. These changes were studied in finite element software beforehand to allow the manufacturer to enhance their designs before testing the PV module by the qualification tests [182].

In wind experiments, energy law is used to determine average wind speed [183]. Power law is based on roughness and has been modeled in many symbols such as the National Building Code of Canada (NBCC) [184] and its American counterpart from the ASCE [179]. According to the ASCE standard, there are many procedures to calculate the minimum wind pressure when designing roof systems. The effects of wind on suspended forms of solar arrays measured in wind tunnels are studied in literature. The US Department of Energy has commissioned many researchers to conduct pilot tests to measure the impact of wind speed on flat PV panels [185]. The results of this test showed that upstream flow retaining elements such as barriers can be used to reduce the wind effects on the PV unit. On the other hand, the end plates were found most suitable for large load reduction on plates.

Several studies have been conducted to test models of PV roof panels mounted in the wind tunnel. Reference [186] examined the wind effect of several rows of photovoltaic cells that have been fixed on the roof, and this slag is divided into three different construction models with flat surfaces. The results of the study showed that the front row panels received high pressure and force factors and reduce their effects on the following rows. Reference [187] investigated the lift force on the support structures of the PV plates. The study concluded that wind loads on photovoltaic units could be reduced using the appropriate building elements. Reference [188] tested a constricted construction model in the wind tunnel to represent photovoltaic modules installed on flat roofs. The measured pressure on the roof of the building was measured at one time. The study recorded fluctuations in the net pressure coefficient on the plates, while the lateral spacing between the plates varied during these tests. The leading edge recorded a slight variation. The study results indicated that changing the clearance height and panel spacing will not subject additional momentous variations on the overall pressure of the PV panels. Reference [189] tested an array of six PV modules placed in parallel in the wind tunnel, where the wind speed was 15 m/s. The study was conducted to evaluate the location of the maximum torque enforced on the modules with the critical loading angle of the subjected wind. Besides, the study introduced a linearized model to predict the peak torque of the system for the used modules.

It is known that the efficiency of the PV module depends entirely on meteorological data such as solar radiation, ambient temperature, relative humidity, and wind speed. Reference [190] studied the effect of ambient temperature and wind speed on the efficiency of solar photovoltaic solar module in the northeastern region of India. The researchers used statistical analysis in the study; the results showed a moderate positive correlation between unit efficiency and wind speed. Reference [191] conducted a study on convective heat losses and its relation to the cooling effect of wind. The study demonstrated the importance of employing actual velocity distributions for different locations on the top roof. The wind velocity measurements are performed at nine variable locations for three different wind directions (0°, 45°, and 90°). The study revealed that local velocities on different locations can vary up to 62%. Also, the wind impact on a solar collector's performance can be assisted at different locations of the roof of a building. The study estimated that for a sunny day, thermal energy gains can reach 17% higher on windward than leeward locations.

Reference [192] clarified the negative impact of high wind velocity that reduces the efficiency of building-integrated photovoltaic/thermal (BIPV/T) systems. The wind stream on the PV module surface limits the heat transferred to the surrounding air by enhancing convection losses. As a result, the outflow from the plenum behind the panel reduced. As there are two purposes for the BIPV/T systems which are generating electricity and heating ambient air using absorbed solar energy, the study observed that heat losses from the solar panel and its thermal efficiency are affected by wind direction.

High wind speeds enhance cell performances by reducing the cell operating temperatures. Many literature correlations quoted an efficiency gain of 0.7% for a 1 km/h rise in wind speed [193]. Such a gain is considerable if we take in account the relatively low maximum efficiencies possible with present technologies and the new large-scale PV installations. Reference [194] adopted an approach to study the direct or indirect influence of wind on PV system performance relating the heat transfer of roof-mounted PV panels in high temperature regions. The study concluded that the gain in PV cell efficiency increases as the wind speed increases to 5 m/s compared with the wind speed increment beyond 5 m/s.

Since the temperature of the PV panel is a dynamic result of changes in incoming solar radiation, and to determine the response time of the PV for heat, many researchers conducted measurements within a wind tunnel with control of the speed and direction of wind flow on the surface of the fin plate. Tests were conducted in the dark to avoid heat loss by radiation. In practical operating conditions, the temperature of the PV panel is subject to ambient temperatures and the fluctuation of wind speeds and its trends [195]. These variables are not available in indoor experiments where the conditions are controlled. Reference [95] proposed a new thermal model and enhanced the atmospheric conditions and their effects on the PV panel and the installation method. The results of the study clarified the thermal behavior of the PV module exposed to progressive winds from low to strong. The PV panel model was validated under different wind speeds.

Reference [196] focused on the cooling effect of wind on PV cell temperature. The study showed that for most installed PV modules in Bolzano (Italy), the wind data included in the models predicted PV cell temperature better than standard approaches that do not include wind data. The study concluded that the wind data from numerical weather prediction models were able to replace in situ wind measurements. This result is true when the numerical weather prediction models were used as model input. Also, the prediction improved considerably in comparison to the standard approach.

The standard test conditions (STC) are used usually to measure the solar cell efficiency. These conditions are the PV cell temperature of 25 °C, irradiance of 1000 W/m^2, and air mass of 1.5. It is very difficult to meet these conditions at outdoor installations. The PV module temperature shows dynamic variability under outdoor conditions, but it is related to other environmental parameters [197]. Photovoltaic cells are mainly affected by the cell temperature, as well as the energy yield. System temperature of free cells can reach up to 60 °C on a summer day without a cloud in Central Europe. This rise in the temperature of the cell leads to a significant reduction in the production of electric power. There are also many ritual variables such as incoming radiation and related meteorological parameters and wind, the most important parameter affecting cell temperature. Currently, the standard approach used to assess cell temperature for models is based only on radiation measurements and ambient air temperature. Wind effect is not included in the effects on cell temperature [194]. Many authors (such as Refs. [95, 196–198]) have used a different approach in the survey that includes the effect of wind in the estimates of the temperature of the PV unit [195]. The wind has a cooling effect up to 15–20 °C for a wind speed of 10 m/s in solar radiation around 1000 W/m^2. References [137, 197–199] tested a number of different models and verify the integrity of the results using wind data at the site whether variables are measured directly from or near the location of PV cells. Unfortunately, on-site wind measurements are rare, and there is a need to replace those data with numerical weather prediction.

Reference [137] conducted a study to make use of passive cooling of PV by natural convection. The study evaluated the performance of PV cell with passive fin cooling which resulted from natural ventilation. Many parameters that affect PV panel performance as tilt angle, solar radiation, air temperature, and wind velocity as well as fin size were considered. The study concluded that the PV cell efficiency decreased linearly with the air temperature increase, but it increased with the increasing wind velocity. The fin height effect on the PV module efficiency was very slight. The average increment in the efficiency of PV panel with fins was higher than that of PV panel without fins with about 0.27–1.14% under the different conditions of the study.

Reference [200] reviewed in detail the effect of dust, humidity, and wind speed and pointed out that deposition of dust and its settling on the surface of photovoltaic cells caused its low efficiency. On the other hand, increasing wind speed pulls more heat from the surface of photovoltaic cells, causing cooling effect. Besides, the high wind speed reduces the relative humidity of the atmosphere in the surrounding areas leading to better efficiency. High wind speeds also raise sand and dust in air, reducing the amount of solar radiation coming in and, as a result, reducing the performance of photovoltaic cells. As a summary, the dust, humidity, and air velocity are combined side by side to affect the performance of photovoltaic cells. Therefore, it is better not to study each parameter separately from the rest of the variables when the efficiency of the cell is estimated due to the adverse effects and mutuality between these variables. Photovoltaic systems have many benefits not only electricity generation, but also it provides shading for building envelopes that reduce solar radiation heat gain. Reference [201] studied a problem correlated with photovoltaic system installation onto building envelopes. The inappropriate air spacing between the PV system and the building envelope is a crucial problem. It leads to increase PV module temperatures which results in decreasing its efficiency and maximizes the heat gains through the roofs and walls. The study introduced a design for an adjustable testing model. This design is able on varying the inclination angle and air space of a photovoltaic module. A practical experimental test is used to validate the simulation model. The experimental results revealed that there are some discrepancies for the wall surface temperatures accompanied with the predictions of the module's temperatures. An appropriate air gap reduces the quantity of heat transferred through the walls and roofs by at least 1.85 kWh/m^2 per year. However, increasing the air gap width may lead to an unaesthetic appearance that tends to reduce the heat gain through the building envelope. The air gap spacing is limited due to the unshaded area increase and the increases of the building outside temperatures. As a result, the heat gains through the building tend to increase.

Reference [202] conducted an extensive outdoor experiment on photovoltaic modules mounted on the ceiling to study the lifting forces on the modules. Measurements of pressure bands were taken at the top and bottom of the panel, wind speed, and wind direction to assess the wind load. The results of the study showed that the maximum lifting force placed on the solar panels depends on the direction of the wind, and it has a corresponded pressure coefficient, Cp, value of -0.55. The upward and downward differential pressure coefficient, ΔCp, values were 0.3 and 0.2, respectively. These coefficients recommended for the downward acting force for a single solar panel on such rooftops.

Reference [203] tested the scaling model of the photovoltaic solar module in the open wind tunnel. Power transducers were used to measure drag and lift forces on photovoltaic units. The study concluded that the force coefficients on the PV panel increased with an increase in tilt angle from 0° to 90°. As expected, wind speed increased with a higher power factor. Reference [137] used computational fluid dynamics (CFD) to study wind-loaded aerodynamics on PV panels mounted on the ground. To verify the theoretical results, a large-scale experimental model was constructed and measured. Distribution results showed both wind directions on the Windward and Leeward sides of the panel.

Reference [204] measured practically the pressure subjected on the top and bottom surfaces of the PV module for 24 individual panels. The study was conducted in the wind tunnel for four different wind directions. The results of the study showed that the distribution of wind pressure on the surface of the module is similar to the average level of the front wind (0° and 180°), asymmetrical in other wind directions. The study concluded that for large PV units, the gap between the plates is necessary as the surface pressure of a module is affected. Increasing the inclination angle increases the pressure on the module surface. The average pressure on the photovoltaic module under exposure to the open terrain of the wind is smaller than that under the wind exposure which is smooth.

Reference [205] tested experimentally in the wind tunnel the effects of airborne dust concentration on the performance of photovoltaic cells due to the accumulation of dust on its surface to assess the impact of wind speed. Four wind speeds and four dust concentrations were used to investigate their effect on the PV module performance. The results showed that the deposition of fine elliptical dust and its accumulation of photovoltaic cells affect its performance. The wind speed has an impact on the low performance of the PV module, as the decrease is greater in conditions of high wind speed compared to low wind speeds. During high winds, high permeability of light is generated through paint due to wind effects that removes dust deposits. As a result, the PV cell performance deteriorates due to dust accumulation with wind speed increases. Higher dust concentrations resulted in higher accumulation on the cell surface. Airborne dust concentrations do not affect by the sediment logical structure of dust coatings in contrary to wind speed. The accumulation and deposition of fine Aeolian dust particles on the glazing of PV cells affect the performance of these cells significantly.

Wind forces are the major cost inducement for rooftop- and ground-mounted PV systems in all climate terrains. The complete elimination of wind forces is an unrealistic issue, but even minor reductions in its load can decrease the PV system costs and increase the available numbers of roofs for such systems. Reference [206] estimated that if the wind never blows, the structural costs can be eliminated up to 75 percent. Also, the reference estimated a reduction of 30–35% in wind forces can be achievable for ground-mounted PV systems that are not subject to heavy snow. Many valuable methods suggested increasing the reduction as staggering the arrays, spacing the panels to allow the wind to pass between them, using border fencing, and changing code can. The wind force reductions lead to smaller structural systems with lower cost reductions. Reference [207] showed that if a 20% reduction in maximum wind speed is achieved, a reduction in structural costs with about 20% is resulted. However, the reduction of wind loads affects the system performance and must be considered carefully. As previously mentioned, airflow around module reduction may limit panel cooling that as a result reduces module performance.

5.7 Dust Effect on PV

5.7.1 Background

The energy that reaches the Earth from the sun in 1 h is approximately equal to the amount of energy the Earth needs for a whole year. The sun's surface temperature rises up to 5800 K, while the arrived energy to the atmosphere is estimated at 1367

W/m^2 [4]. A whole range of optical spectrum lies at low temperatures, specifically in the infrared section. The visual range contains diffuse radiation that makes the light has higher energy, which is the sum of direct radiation and scattered radiation [208].

When solar radiation enters the Earth's atmosphere, the molecules of this cover divide this radiation into three parts. One part is absorbed, and the second part clutters, while the third part cross through it [209]. The ozone layer in the atmosphere absorbs the ultraviolet radiation from the sun's rays. In the same time, the CO_2 and water vapor particles absorb a large part of the infrared [210].

The solar cell converts the incident radiation into electricity. However, the solar cells exist in areas prone to the sun; also they are exposed to weather conditions that disproportionately affect them. In this section, we will not discuss the effect of air factors studied previously, but we will focus on the dust impact on the efficiency and performance of the solar cell.

The dust is known as solid fine particles that have a diameter less than 500 microns. The minute pollen, bacteria, and fungi are considered as dust. Also, the microfiber separated from clothing, carpets, and fabrics is known as dust when it settles on surfaces. The deposition of dust depends on several factors and environmental and weather conditions. The movement of pedestrians and vehicles exhausts pollutants in addition to the results from the movement of the tires; volcanic eruptions, pollution, and wind can raise dust and scatter it in the atmosphere [211].

Dust deposition depends on the dust properties (chemical and physical) as well as the environmental conditions (site-specific factors, the features of the environment, and the weather conditions). Surface roughness, the angle of inclination, humidity, and wind speed on the dust deposition also affected the dust settlement [212].

The sand and dust accumulation on the surface of the photovoltaic modules (PV) has a negative impact on their performance, and this has been confirmed by both field studies and laboratory experiments [213]. The dust particles prevent the arrival of the falling photons to the photovoltaics and thus reduce the electrical power generated by the unit. This problem is clear and definite in dry and hot areas such as the Middle East and North Africa regions, where winds move the sand and dust particles and drive it for hundreds of kilometers sometimes [214].

These areas are considered suitable locations for PV installations as a result of higher average radiation levels and the availability of land. Moreover, the economic growth in countries, as Kuwait, the United Arab Emirates, Saudi Arabia, and Qatar, has led to the construction of many new buildings that provide a very good potential for the use of solar modules.

Sustainability is increasingly important in these projects on an ongoing basis for clients, engineering companies, and civil society organizations calling for the adoption of green buildings. So far no definitive solutions have been found in the problem of the accumulation of dust on photovoltaic units, which limits their productivity. No radical solutions have been found that can be translated into an engineering tool that can be used by designers and engineers to assess environmental conditions and work on and include PV in the construction project at different locations [215].

The photovoltaics systems' dust deposition case relies on two basic factors that affect each other, namely, the dust specifications and the local environment. The local environment for the site includes the nature of the prevailing activities including the human factors, in addition to the style of construction of the solar cell system and its properties, which are the surface finishes, orientation and installation height. Also, environmental features (vegetation type) and weather conditions play an important role in this regard. The properties of the dust (type, chemical, biological, and electrostatic properties, size, shape, and weight) are no less important than the accumulation/aggregation. Similarly, the style of an end surface of the solar cell (PV) is affecting issues. The sticky surface (furry, rough, adhesive residue and the electrostatic buildup) is more susceptible to the accumulation of dust from the least sticky ones, which of course is a smoother surface. It is known that dust enhances dust, i.e., that at the beginning of the stability of the amount of dust, it tends to attract and encourage more settlements, which means that the surface becomes more willing to collect dust [216].

Dust accumulates by gravity to oblique horizontal surfaces more, but the amount of accumulation depends on the prevailing wind movement. Low-speed winds encourage dust settlement; on the contrary, the high-speed winds hamper the dust settlement and have a cleaning effect. Therefore, the method of installation of PV systems, taking into account the direction of the prevailing winds and the movement, can either increase or decrease the dust settlement and accumulation in specific places of PV systems [217].

No one can deny the growing interest in photovoltaic cells more than ever between developed and developing countries due to the environmental and economic benefits of converting solar energy into electrical energy. Currently, it is allocated more of the budget on photovoltaic systems for assigning traditional electrical systems. There are a large number of studies conducted on the effect of different variables affecting the efficiency and performance of photovoltaic cells. A wide range of research studies have shown that there is a decline in photovoltaic cell performance.

As there is a vast number of researchers in this field, we will review only the results of those who have worked in Iraq's neighboring countries with similar environment and atmosphere to those of Iraq.

In 1942, Hottel and Woertz study the effect of dust on solar energy systems. The study was conducted in 1940 using three sets of flat plate solar thermal collectors located in the area close to the thermal power plant in the United States. The researchers found that there is a 1% deterioration in performance due to the dust collected/dirt accumulated on a glass plate inclined at an angle of 30° from the horizon. The maximum decline in the performance of the solar collectors is 4.7% in an exposure period of 2 months [218]

In Saudi Arabia, which is one of the desert areas, Nemo and Seid studied the efficiency of thermal panels and photovoltaic cells for more than 6 months. The results of the study declared a deterioration of up to 26% and 40% for thermal panels and photovoltaic cells, respectively. Unfortunately, the study failed to determine the dust pollution levels during the testing period [219]. Salem et al. investigated the accumulation of dust on the long-term PV system – solar village near Riyadh (Saudi Arabia). The study was carried out using a PV system leaning on the horizon by an angle of 24.6°, with cleaning cells every day. The results showed a decrease by 32% in the performance of the solar array due to the accumulation of dust, after 8 months of use [220].

The capital of Saudi Arabia, Riyadh, was hit in March 10, 2009, by a severe dust storm that lasted several hours. This storm represents one of the abused dust storms that passed through the Kingdom of Saudi Arabia in the past two decades. This storm that did not last long with dense dust caused lack of vision in all parts of the city of Riyadh. Maghrabi et al. studied the changes in meteorological factors, such as the optical depth of aerosols (AOD), infrared (IR) temperature, and the degree of the sky emissivity in the atmosphere, before, during, and after the storm. The results revealed significant changes in each of the studied factors as a result of this event. The theoretical simulations using the SMART program showed significant changes in the spectral components of solar radiation and global radiation, which increased by 42% and 68%, respectively. The diffuse components increased by 44% compared with the previous day, which was a clear day. The infrared temperature and emissivity also increased by 24°C and 0.3, respectively, after 2 h from the arrival of the storm [221].

Wakim conducted a study on the performance of solar cells in Kuwait City that has a dusty desert climate. Sand accumulation led to a decline in PV power generation by 17% after 6 days. The study also indicated that the dust accumulation impact on the performance of the photoelectric was the higher spring and summer (20% in 6 months) than the autumn and winter months [222]. Sayegh conducted a search of the dust accumulation effect on a flat plate solar. The experiments were conducted using seven flat plate collectors, six of which are arranged in three pairs and exposed to the sun in inclination angles of 0°, 30°, and 60°, while the seventh collector was put vertically in tendency of 90°. During the experiments, one collector in each pair of collectors was cleaned on a regular basis, while others were retained without cleaning. The amount of solar energy absorbed from the non-cleaned collectors was compared to those resulting from clean sheets. The study showed that the accumulation of dust on the board rate was about 2.5 g /m^2/day between the months of April and June [223]. Sayegh et al. investigated the effect of dust accumulation on tilted glass plates in Kuwait. The study found a decrease in the permeability of the glass ranges from 64% to 17% of a slope angles ranging from 0° to 60°, respectively, after 38 days of exposure. The study revealed a 30% decrease in the gain of useful energy from horizontal collector after 3 days of dust accumulation [224].

Qasim et al. focused in their study on the dust impact on the spectral transmittance of the optical units. The samples were collecting dust in the form of crude as well as the accumulated dust on the exposed sheets of glass at different inclination angles. The spectral transmittance was identified for the samples. The samples' spectral transmittance difference between the upper, middle, and lower samples was determined for various degrees of panels' inclination. The worst result was at 30° inclination angle of 4.4% compared with 0.2% for the tilt angle of 90° [225].

In Qatar, Touati studied the sensitivity range of solar photovoltaic modules for the Qatari environment such as dust, temperature, and relative humidity. The results showed that the monocrystalline solar cells had high efficiency, such as 85% compared to 70% for the amorphous ones. Also, the accumulation of dust caused the most important decrease in the efficiency of a silicon cell, amorphous and monocrystalline, compared to the effects of temperature or humidity [226]. In Qatar also, Touati held a search on the sensitivity of different types of solar photovoltaic technologies toward dust, temperature, and relative humidity. The results showed that the dust has a significant impact on reducing the efficiency of solar cells that accumulate. The amorphous PV is more reluctant for dust settlement compared to monocrystalline, so it is more suitable for implementation in desert climates such as Qatar. The study estimated that 100 days of dust accumulation on monocrystalline PV panels caused a reduction efficiency of 10%. This limitation makes solar PV a reliable source of energy [136].

Darwish et al. reviewed the interference between the impacts of some environmental variables with the dust on the PV performance. They also discussed the impact of the dust properties and its effect on PV systems. The study showed significant main points that need further research, such as dust characteristics (size, geometry, and electrical deposition behavior). As to determine the optimal geographical location/climate, it must be taken into account the optimal tendency, working height, and orientation, to achieve the best solar radiation falling patterns [140]. Darwish et al. also studied many of the environmental factors that affect the PV productivity and dust in United Arab Emirates. One of the main reasons for the deterioration of PV systems used in both large and small systems is the accumulation of different types of dust, which reduces efficiency. The dust contents represent a mixture of different pollutants determined by the geographical location and human activities at this location. Many studies have focused on the dust's effect on the performance of photovoltaic effect, but few studies look at the effect of dust on the type of contaminated cell performance, and more research done on the polluted dust impact indoor while few of them studied it outdoors. This article revised the effects of pollutants on the types of PV performance experimentally [227].

Kazem et al. studied the performance of photovoltaic systems in the desert climate of the Sultanate of Oman by studying the effect of dust on the deterioration of the efficiency of the photoelectric system due to the deposition of different types of pollutants. Experiments were conducted on the effect of air pollutants such as red soil, ash, sand, calcium carbonate, and silica on the produced energy. The results showed that the type and level of deposition of contaminants strongly affect the low photovoltaic voltage and energy. The results also showed that ash dust particles have the greatest impact on the performance of photovoltaic units compared to other pollutants studied. The highest reduction recorded in the photovoltaic effort was 25% when using ash contaminants [228]. Kazem et al. investigated the effect of the physical properties of different types of dust on the performance of solar PV panels. Six types of dust were collected from different parts of the northern region of Oman. The results of the study showed that the influence of Sohar and Saham dust was more negative on the PV performance than the other types of dust studied due to its moisture content, which reached 52.21% in dust of Saham and 45% in the Sohar dust. In contrast, the dust of the other four locations was lighter and less humid.

However, the study concluded that in the northern region of Oman, the impact of dust on PV performance is lower than in other Gulf countries. [212]

Sukhatme considered that the desert areas are best suited for the use of photovoltaic power stations due to the availability of abundant sunlight throughout the year. Many studies are conducted nowadays discussing ideas for the setup of vast solar panel stations in the desert countries and export energy to other countries. In such stations, more manpower and hardware will be needed to help clean the PV panels, especially after the dust storms, which are frequent in such areas [229].

Nahar and Gupta conducted a study on the impact of dust on the permeability of a set of glass panels in the Thar Desert in India. The study showed that dust deposition decreases with increasing inclination of the panels from the horizon. The decrease in the glass permeability were 19.17%, 13.81%, and 5.67% for tilt angles of 0°, 45°, and 90°, respectively [230].

Sayyah et al. declared that the deserts can supply the world's solar electricity using a variety of solar technologies including concentrated solar power systems (CSP), photovoltaic (PV), concentrated photovoltaic (CPV), and the wind. The researchers explained that the Mojave Desert in the United States can meet the electricity requirements of the whole American states. The solar energy available in these arid areas offers enormous potential beyond largely from the need for the current market. The study showed that the solar energy stations should be kept clean of dust in order to maintain the high efficiency of the transmission and reflection of sunlight. Dust associated with the sandstorm left the mass of it deposited on the surface of cells in order to prevent entirely sunlight from reaching the compound. The conducted study measured a decrease in the permeability of the sun through the glass front panels of photovoltaic devices which can vary from 5% to 30% per annum depending on the deposition of dust [231].

5.7.2 Dust in Iraq

In his address to the Nairobi Conference, Mr. Martin Kobler, representative of the Secretary-General of the United Nations in Iraq, indicated that in the coming years, the country would experience 300 dust storms if proactive measures were not taken to resolve the problem. Mr. Kobler said that environmental issues affect everyone in Iraq. Dust storms, desertification, and water scarcity are just three of the many pressing issues, and we must begin to face these challenges with each of us.

Iraq suffers from a nearly three major wars and unjust siege for 13 years and two decades of drought. This has caused the birth of a new dust basin in the region. Iraq suffers chronically from overgrazing and more plowing for several years. The country faces a loss of green soil that depends on the waters of the Tigris and the Euphrates because Turkey, Syria and Iran reduced his water share. This reduction in the water quota has led to a decrease in water levels in the river, reduced and dried marshes, deteriorated irrigation infrastructure, decreased irrigated area and increased area of fallow land. So the Fertile Crescent, the cradle of civilization, began to turn into a dust bowl [232]. Dust storms are recurring with increasing frequency in Iraq. The presence of dry soils and windshield with constant winds during much of the year has led to the further formation of dust storms and sandstorms, which are now a major hazard that should be avoided and guarded. Large swathes of Iraq, Syria, Jordan, and North Africa have become dusty vessels and a source of dust storms affecting Iraq and the rest of its neighbors.

In the southern desert, where the vegetation in the minimum and the availability of silt and sand, and even in most wetlands adjacent to the Tigris and Euphrates regions, the desertification began creeping, which makes it a problem [233]. While a major dust storms affect the cities, and caused serious damage in the origin area of the storm. The surrounding areas are also affected by dust storms and sand storms. Sandstorms are very clear evidence of desertification, soil erosion, and its fragmentation. Deforestation through overgrazing or unforeseen tillage, or wind erosion, causes small soil particles to move away with the air. These small soil particles can fly in the air for long distances, leaving behind large sand particles, and so dust storms begin. These local phenomena cause the formation of sand dunes and hurt farming and grazing areas. The sandstorms can be regarded as the last stage in the process of desertification [234]. Drought conditions in Iraq affect not only the ability to rain-fed agriculture but also change the hydrological regime of the Tigris and Euphrates conditions that rely heavily on irrigation [235]. Also, the amount of precipitation in the winter and spring was lowered. Warm surface temperatures, also, caused a lot of evaporation of the available surface water, exacerbating the drought [236].

Iraq strongly suffers from land degradation and desertification problems, especially in the central and southern parts. The problem affects mainly the natural ecosystem and human social order. Desertification causes economic and social provocation (marketing, income, human health, institutional support and poverty) and undermines food production and political stability [237]. In general, indicators can be adopted for the classification of the degree of severity of sand-dust storms depending on the wind speed and clarity of vision. Reference [235] classified sand-dust storms into three grades. The lowest degree is for a weak sandstorm, when the wind speed is 6 (Beaufort) and the visibility ranges from 500 to 1000 m. A strong secondary sand-dust storm will happen when the wind speed is in the power of 8 and vision differs from 200 to 500 m. The strong sand-dust storms take place when the wind speed is in force 9 and the visibility is less than 200 m.

Sandstorm and dust storms in Iraq occur in the spring season and cover half of the total frequency of sandstorms (the most dangerous storms and powerful are taking place in the spring season). The dust storms in the summer and autumn become the second place in terms of power and repetition. The month of April is the most important time when the occurring sandstorms are the most dangerous with high pace, followed by March and May, and the least months to get these storms are December and January. The pace of sand-dust storms increased over the last decade, and the situation cannot improve because of the severe pressure on the Earth's resources in a short period of time. With the increasing global warming, and with the increasing decline of water resources, the sand-dust storms become more influential and damage [238].

5.7.3 Iraqi Dust Specifications

A study by the US Army on the dust of various deserts of the world has shown that the physical and chemical properties of sand and dust in these deserts vary greatly. Soil and dust collected from areas of military activity in Iraq have concentrations of interactive chemical substances [239]. These components are primarily salts and carbonates that have been highly concentrated in all dust samples examined, in addition to silica (quartz), which is usually the main component with a concentration less than 80% of the sample mass [240]. The interactive chemical constituents of many samples collected in the desert of Iraq have the ability to corrode metal parts. A wide range of clay minerals were found in Iraqi dust samples [241]. The average particle size in Iraqi dust samples was found to be much smaller than that of US weapon designs, which caused failure of some of it [242]. The average particle size of the dust taken from the vehicles in Iraq is much smaller than the particle size of the bulk soil samples. Moreover, the sample contained compounds with high carbonates and sulfates concentration. All the measured concentrations can cause high pollution to the environment and great harm to humans [243]. The tested dust samples consisted of large amounts of salt-soluble carbonates, chlorides, and sulfates [244]. There are also parts of titanium oxides (TIO_2) and aluminum (Al_2O_3), iron (Fe_2O_3), sodium (Na_2O) and potassium (K_2O), and phosphorus (P_2O_5) [3]. There are also anions soluble in water in a wide range of concentrations. Sulfate (SO_4 2-) and chloride (Cl) are presented at different concentrations in each of most of the samples and models.

Reference [245] found that the dust types whether in the street or indoors of an urban area could be a source of contamination with heavy metals derived from three main sources: industrial, automotive activities, and treated materials. These materials are lead, zinc, cadmium, nickel, and chromium which were found in the street and house dust. The study showed that the concentrations of these substances in Baghdad were 0.86, 0.105, and 10.88 mg/m^3 for lead, zinc, and iron, respectively.

5.7.4 The Iraqi Studies on the Effect of Dust on PV Systems

The most important problem faced by the advocates and supporters to spread the electricity production plants using solar cells in Iraq is the density of dust in the atmosphere and deposition on the surface of solar panels. The increasing dust densities in the atmosphere is causing the amount of sunlight reaching the surface of solar cells to reduce, and this leads to low performance efficiency [246]. Many Iraqi researchers studied the effect of dust storms on the overall solar radiation rates for the city of Baghdad. A study of a dust storm that occurred in 2012 in Iraq manifested a significant impact on the total solar radiation. This storm caused a decrement in solar radiation from its natural rates significantly [247, 248].

Reference [249] collected samples from three areas in Baghdad during a dust storm that occurred on June 18, 2009. The study aimed to examine the particle size and composition. Six minerals detected in the samples are calcite, quartz, dolomite, kaolinite, gypsum, and plagioclase. The study found some traces of lead, nickel, and chromium in the samples. The sample's particle size revealed mostly between 32 and 45 microns. The danger of dissolved salts in the dust particles is in the potential impact on the pH of natural water, groundwater, or soil [250]. The presence of carbonate ions airborne (CO_3^{2+}) in the dust that may cause an insulator in the atmosphere and can affect the characteristics of the atmosphere as it is a base, it will absorb SO_2 gases and nitrogen oxides and converted into ions of SO_4^{2-} NO_{3-} and deposited it on the surface [251, 252].

It is necessary to develop technologies to remove dust deposited on the surface of solar panels to ensure its long range. One of the ways to remove dust is the natural way, it depends on rainfall and wind movement, and this is an important way. The exploitation of nature is made possible by simply selecting and directing cells to other directions except the horizontal, making the solar panel receive a larger amount of radiation [253]. Another way to remove dust is using electricity. If the surface of the PV module is charged, it will attract particles of opposite charge and repel the molecules of the same charge [254].

Reference [255] studied the problem of dust accumulation on the surface of solar panels that causes a severe reduction in the system performance. The researcher designed a new technique to reduce the accumulated dust on the surface of solar panels and compare the new technology with fixed solar panels installed at angles of 30° and 45°. The new technology operates using a mobile platform attached to the two axes of the sun tracking system bonded to the PV panels. The new technology approved that it can reduce the amount of dust accumulated on solar panels daily through the daily use of the system mechanism. When the sun goes down, the direction of the solar panels is changed from west to east on the horizontal axis (azimuth), and the angle of the photovoltaic angle changes to more than 90° (about 95°) on the vertical axis (height) [256]. This process takes place every day at sunset. This movement and vibration resulting from it will benefit in vibrating the dust particles adhering to the surface of the PV panels. So, the shift in the tilt angle makes the dust particles move on the surface of the PV module, making it easy to get rid of them completely by the force of gravity. The results indicated that the maximum loss in the performance of fixed cells due to dust accumulation was about 31.4% and 23% for inclination of 30° and 45°, respectively, after exposure to external weather conditions for 34 days. The maximum loss of power produced from PV panels using the new technology was about 8.5% for the same period [257].

Reference [258] studied the impact of natural deposition of dust in Baghdad City on the PV panels. The accumulated dust thickness increases with the passage of time. Thus, increasing the PV panel angle of inclination leads to the reduction of losses, due to accumulated dust decreased. The accumulation of dust on the surface of the panel PV causes a decrease in performance of about 35–65% of the month without cleaning. Changing the tilt angle has less impact on the power resulted from the accumulation of dust [259]. The increase in the average wind speed in some months of the year caused a partial reduction of the accumulated dust on the surfaces of solar modules. Reference [260] manifested that the average wind speed for the months of June and July in the city of Baghdad is 6.19 m/s and 6.04 m/s, respectively. The dry weather and the existence of adhesion strength between the atoms of dust and glass for PV panel cover provide a reason for the dust deposition. Rain pour in some months of the year cleans naturally the PV panels, especially in the months of February and March.

Reference [261] conducted practical experiments in the outdoors in the winter months of the city of Baghdad, Iraq, to measure the impact of the pollutants resulting from highways on the performance of PV cells. The investigations were carried out using three cells. The study revealed that air pollution causes a deterioration of the performance of PV cells, even during a short period, such as two months of staying outdoors without cleaning. Also, the study showed that the resulting photovoltaic power of the contaminated arrays dropped 12%, while the power of the cell that was cleaned normally (by the rain and wind) dropped about 8% compared with the always clean cell. The laboratory examination revealed that there are high concentrations of particulate matters in the collected contaminants that came from the automobile exhaust soot. The researchers did an interesting study for a number of detergents and their impact on the output of the PV cells. The results showed that the use of sodium solution as well as alcohol kept the cell performance at high rates. At the same time, the use of distilled water reduced the performance of the PV cell by about 14% after a period of exposure of 6 weeks. The study concluded that in the end, there is a high possibility for the use of PV modules in Iraq instead of generators operated with diesel or gasoline.

References

1. Duffie JA, Beckman WA (1991) Solar engineering of thermal processes. John Wiley and Sons, New York
2. Fröhlich C (1991) History of solar radiometry and the world radiation reference. Metrologia 28:111–115
3. Gueymard CA, Myers DR (2008) Solar radiation measurement: progress in radiometry for improved modeling. In: Badescu V (ed) Modeling solar radiation at the earth surface. Springer, Berlin, pp 1–27
4. Gueymard CA (2004) The sun’s total and spectral irradiance for solar energy application and solar radiation models. Sol Energy 76(4):423–453
5. Mousazadeh H, Keyhani A, Javadi A, Mobli H, Abrinia K, Sharifi A (2009) A review of principle and sun-tracking methods for maximizing solar systems output. Renew Sustain Energy Rev 13:1800–1818
6. Dickinson WC, Cheremisinoff PN (1980) Solar energy technology handbook. Butterworths, London

7. Kumar L, Skidmore AK, Knoles E (1997) Modeling topographic variation in solar radiation in a GIS environment. Int J Geogr Inf Sci 11(5):475–497
8. Earth radiation budget (http://marine. Rutagers, Deu / mrs / education class / yur / erb .html)
9. International energy agency (http://www.iea.org/)
10. Earth radiation Budgest earth Radeation budget (http:// marine.Rutgers. edu/mrs/education/classs/yuri/erb.html) NASA langlely research center (2006-10- 17). Retrieved on 17 Oct 2006
11. Duncan CH, Willson RC, Kendall JM, Harrison RG, Hickey JR (1982) Latest rocket measurements of the solar constant. Sol Energy 28:385–390
12. Kondratyev KY (1965) Radiative heat exchange in the atmosphere. Pergamon Press, New York
13. Williams LD, Barry RG, Andrews JT (1972) Application of computed global radiation for areas of high relief. J Appl Meteorol 11:526–533
14. Khatib T, Mohamed A, Mahmoud M, Sopian K (2012) Estimating global solar energy using multilayer perception artificial neural network. Int J Energy 6(1):23–33
15. El-Shazly RM, Feasibility of concentrated solar power under Egyptian conditions, MSc Thesis, University of Kassel, Cairo University (Egypt), 2011
16. Tomson T (2008) Discrete two-positional tracking of solar collectors. Renew Energy 33:400–405
17. Chaichan MT, Abaas KH, Kazem HA, Hasoon F, Aljibori HS, Ali A, Alwaeli K, Raheem FS, Alwaeli AH, Effect of design variation on saved energy of concentrating solar power prototype, Proceedings of the World Congress on Engineering, WCE III 2012, London, UK, 2012
18. Asia/Pacific PV Markets 2010 (http://www.solarbuzz.com/AP10.htm)
19. Green MA (2003) Crystalline and thin-film silicon solar cells: state of the art and future potential. Int Sol Energy Soc ISES 74(3):181–192
20. Duryea S, Islam S, Lawrance W (2001) A battery management system for stand-alone photovoltaic energy systems. IEEE Ind Appl Soc 7(3):67–72
21. Durisch W, Kiess H, Crystalline silicon cells and technology, Third Generation Concepts for Photovoltaic Conference, Osaka, Japan, 12–16 May 2003
22. Chouder A, Silvestre S, Sadaoui N, Rahmani L (2012) Simulation of a grid connected PV system based on the evaluation of main PV. Simul Model Pract Theory 20(1):46–58
23. Thongpao K, Sripadungtham P, Raphisak P, Sriprapha K, Ekkachart O (2010) Solar cells based on the influence of irradiance and module temperature in, Electrical Engineering/Electronics Computer Telecommunications and Information Technology (ECTI-CON), International Conference , Chiang Mai, Thailand, pp 153–160
24. Burari FW, Sambo AS (2001) Model for the prediction of global solar radiation for Bauchi using meteorological data. Nigeria J Renew Energy 91:30–33
25. Al-Salihi AM, Kadum MM, Mohammed AG (2010) Estimation of global solar radiation on horizontal surface using meteorological measurement for different cities in Iraq. Asian J Sci Res 3(4):240–248
26. Kalogirou S (2009) Solar energy engineering: process and systems. Academic Press, London
27. Abdullah FS, Ali FA (2012) Estimation the effects of each site factors, time factors, and optical factors on absorbed solar radiation value that incident on a flat plate solar collector. J Theor Appl Inf Technol 41(2):122–133
28. Jarras J (1987) Feasibility of a fund for financing solar water heaters and projects related to the promotion of renewable energies in Jordan. MEMR press, Amman
29. Li DHW, Lam JC (1999) An analysis of climatic variables and design implications. Architect Sci Rev 42(1):15–25
30. Muneer T (1990) Solar radiation model for Europe. Build Serv Eng Res Technol 11 (4):153–163
31. Li DHW, Lam JC (2004) Predicting solar irradiance on inclined surfaces using sky radiance data. Energ Conver Manage 45(11–12):1771–1783
32. Vartiainen E (2000) A new approach to estimating the diffuse irradiance on inclined surfaces. Renew Energy 20(1):45–64

33. Schaab G (2000) Modellierung und Visualisierung der räumlichen und zeitlichen Variabilität der Einstrahlungsstärke mittels eines Geo– Informationssystems, Kartographische Bausteine, Dresden, 160 pp
34. Al- Salaymeh A (2006) Modeling of global daily solar radiation on horizontal surfaces for Amman city. Emirates J Eng Res 11(1):49–56
35. Khatib T, Mohamed A, Sopian K (2012) A review of solar energy modeling techniques. Renew Sustain Energy Rev 16:2864–2869
36. Kreider J, Kreith F (1981) Solar energy handbook. McGraw-Hill, New York
37. Wardle DI, McKay DC, Recent advances in pyranometry, In: Proceedings of International Energy Agency, Task IX, Solar Radiation and Pyranometer Studies, Norrkoping, Sweden, p 984
38. Zerlaut GA (1986) Solar radiometry instrumentation, calibration techniques, and standards. Sol Cells 18:189–203
39. Lester A, Myers DR (2006) A method for improving global pyranometer measurements by modeling responsivity functions. Sol Energy 80:322–331
40. Michalsky JJ et al (1995) Cosine response characteristics of some radiometric and photometric sensors. Sol Energy 54:397–402
41. Bush BC (2000) Characterization of thermal effects in pyranometers: a data correction algorithm for improved measurement of surface insolation. J Atmos Oceanic Tech 17:165–175
42. Dutton EG et al (2001) Measurement of broadband diffuse solar irradiance using current commercial instrumentation with a correction for thermal offset errors. J Atmos Oceanic Tech 18:297–314
43. Wilcox S (2001) Improving global solar radiation measurements using zenith angle dependent calibration factors. In: Proceedings Forum 2001 solar energy: the power to choose. American Solar Energy Society, Washington, DC
44. Michalsky J (1999) Optimal measurement of surface shortwave irradiance using current instrumentation. J Atmos Oceanic Tech 16:55–69
45. Michalsky JJ (2005) Toward the development of a diffuse horizontal shortwave irradiance working standard. J Geophys Res. https://doi.org/10.1029/2004JD00526
46. Reda I (2005) Using a blackbody to calculate net-longwave responsivity of shortwave solar pyranometers to correct, for their thermal offset error during outdoor calibration using the component sum method. J Atmos Oceanic Tech 22:1531–1540
47. Gueymard CA, Myers DR (2009) Evaluation of conventional and high-performance routine solar radiation measurements for improved solar resource, climatological trends, and radiative modeling. Sol Energy 83:171–185
48. Rajput AK, Tewari RK, Sharma A (2012) Utility base estimated solar radiation at destination Pune, Maharashtra, India. Int J Pure Appl Sci Technol 13(1):19–26
49. Almorex J (2011) Estimating global solar radiation from common meteorological data in Aranjuez-Spain. Turk J Phys 35:53–64
50. Marion B, Kroposki B, Emery K, del Cueto J, Myers D, Osterwald C (1999) Validation of a photovoltaic module energy ratings procedure at NREL. National Renewable Energy Laboratory, Golden
51. Gay CF, Rumberg JE, Wilson JH (1982) AM-PM: all day module performance measurements, Proceedings 16th IEEE Photovoltiac Specialist Conference, San Diego, CA: IEEE, pp 1041–1046
52. del Cueto JA (2007) PV module energy ratings part II: feasibility of using the PERT in deriving photovoltaic module energy ratings. National Renewable Energy Laboratory, Golden
53. Poissant Y, Pelland S, Turcotte D (2008) A compareson of energy rating methodologies using field test measurements, 23rd European PV Solar Energy Conference and Exhibition Valencia, Spain: CANMET Energy Technology Center, pp 1–6
54. Buday MS, Measuring irradiance, temperature and angle of incidence effects on photovoltaic modules in Auburn Hills, Michigan, MSc Thesis, Natural Resources and Environment, University of Michigan, 2011

55. Bashir MA, Ali HM, Khalil S, Ali M, Siddiqui AM, Comparison of performance measurements of photovoltaic modules during winter months in Taxila, Pakistan, International Journal of Photoenergy, Hindawi Publishing Corporation, vol 2014, Article ID 898414, 8 pages, 2014
56. Garcia M, Marroyo L, Lorenzo E, Perez M (March 2011) Soiling and other optical losses in solar-tracking PV plants in Navarra. Prog Photovolt Res Appl 19(2):211–217
57. Cano J, Photovoltaic modules: effect of tilt angle on soiling, MSC Thesis, Arizona State University, 2011
58. Salih SM, Kadim LA (2014) Effect of tilt angle orientation on photovoltaic module performance. ISESCO J Sci Technol 10(17):19–25
59. Salih SM, Salih FF, Hasan ML, Bedaiawi MY (2012) Performance evaluation of photovoltaic models based on a solar model tester. IJ Inf Technol Comput Sci (7):1–10
60. Mehleri ED, Zervas PL, Sarimveis H, Palyvos JA, Markatos NC (2010) Determination of the optimal tilt angle and orientation for solar photovoltaic arrays. Renew Energy, Elsevier 35 (11):2468–2475
61. Emanuele C (2012) The disagreement between anisotropic-isotropic diffuse solar radiation models as a function of solar declination: computing the optimum tilt angle of solar panels in the area of southern-Italy. Smart Grid Renew Energy 3:253–259
62. Ling S, Twidell J, Boardman B (2002) Household photovoltaic market in Xining, Qinghai province, China, The role of local PV business. Sol Energy 73(4):227–240
63. Rahoma UA (2008) Utilization of solar radiation in high energy intensive of the world by PV system. Am J Environ Sci 4(2):121–128
64. Alnaser WE, Eliagoubi B, Al-Kalak A, Trabelsi H, Al-Maalej H, El-Sayed HM, Alloush M (2004) First solar radiation atlas for the Arab world. Renew Energy 29:1085–1107
65. Al-Hilphy ARS (2013) A theoretical and practical study for the incident solar radiation intensity in the Basrah province (south of Iraq). IOSR J Eng (IOSRJEN) 3(9):25–35
66. Sharif SFA (2012) The project, Iraq DESERTEC is the future second electricity supplier to Europe through Turky. Int J Sci Eng Res 3(11):1–8
67. Kanter J, European solar power from African deserts, The New York Times, Retrieved 2009-07-03, 2009
68. Lahmeyer International GmbH, Integrated solar thermal power plants in the Al-Anbar region of Iraq, Terms of Reference for Consulting Services for Preparing a Pre-Feasibility Study, Bad Vilbel, Germany, 2011
69. Abbas MA, Nzsr MK Er (1974) Cloudiness and estimation of incoming solar radiation in Iraq. Pageoph 112(I):234–239
70. Omer MA, Ahmed SA, Al-Jumaily KJ (2013) Solar cycle forcing on Kurdistan-Iraq temperature. J Zankoy Sulaimani- Part A (JZS-A) 15(1):43–55
71. Alasady AMA (2011) Solar energy the suitable energy alternative for Iraq beyond oil, 2011 International Conference on Petroleum and Sustainable Development (IPCBEE), vol 26. IACSIT Press, Singapore
72. Burgermeister J, Iraq looks to solar energy to help rebuild its economy, March 3, 2009. Available at: http://www.renewableenergyworld.com/rea/news/article/2009/03/iraq-looks-to-solar-energy-to-help-rebuild-itseconomy
73. Al-Yahyai S, Charabi Y, Gastli A (2010) Review of the use of numerical weather prediction (NWP) models for wind energy assessment. Renew Sustain Energy Rev 14(9):3192–3198
74. Al-Tarabsheh A, Voutetakis S, Papadopoulos AI, Seferlis B, Etiera I, Saraereh O (2013) Investigation of temperature effects in efficiency improvement of non-uniformly cooled photovoltaic cells. Chem Eng Trans 35:1387–1392
75. Lobera DT, Valkealahti S (2013) Dynamic thermal model of solar PV systems under varying climatic conditions. Sol Energy 93:183–194
76. Zambolin E, Del Col D (2010) Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions. Sol Energy 84:1382–1396

77. Myers D (2009) Evaluation of the performance of the PVUSA rating methodology applied to dual junction PV technology, American Solar Energy Society Annual Conference. National Renewable Energy Laboratory, Buffalo, pp 1–11
78. Hanif M, Ramzan M, Rahman M, Khan M, Amin M, Aamir M (2012) Studying power output of PV solar panels at different temperatures and tilt angles. J Sci Technol 8(14):9–12
79. Skoplaki E, Boudouvis AG, Palyvos JA (2008) A simple correlation for the operating temperature of photovoltaic modules of arbitrary mounting. Sol Energy Mater Sol Cells 92:1393–1402
80. Gregg A, Parker T, Swenson R (2005) A "real world" examination of PV system design and performance. Conf Rec IEEE Photovoltaic Spec Conf 31:1587–1592
81. Charabi Y, Rhouma BHM, Gastli A (2013) GIS-based estimation of roof-PV capacity & energy production for the Seeb region in Oman. IEEE Int Energy Conf Renew Energy 57:635–644
82. Gastli A, Charabi Y, Zekri S (2010) GIS-based assessment of combined CSP electric power & seawater desalination plant for Duqum-Oman. Renew Sustain Energy Rev 14(2):821–827
83. Ghaznafar SA, Fisher M (1998) Vegetation of the Arabian Peninsula. Kluer Academin Publishers, Netherlands, pp 5–38
84. Hughes BR, Cherisa NBS, Beg O (2011) Computational study of improving the efficiency of photovoltaic panels in the UAE. World Acad Sci Eng Technol 5(1)
85. George Makrides G, Zinsser B, Phinikarides A, Schubert M, Georghiou GE (2012) Temperature and thermal annealing effects on different photovoltaic technologies. Renew Energy 43:407–417
86. Mutlak FA, Design and fabrication of parabolic trough solar collector for thermal energy applications, Ph D Thesis, University of Baghdad, March 2011
87. Al-Hilphy ARS (2013) A theoretical and practical study for the incident solar radiation intensity in the Basrah province (south of Iraq). IOSR J Eng 3(9):25–35
88. Chaichan MT, Abaas KI, Kazem HA (2012) The effect of variable designs of the central receiver to improve the solar tower efficiency. Int J Eng Sci 1(7):56–61
89. Kazem HA, Chaichan MT (2012) Status and future prospects of renewable energy in Iraq. Renew Sustain Energy Rev 16(8):6007–6012
90. Nordmann T, Clavadetscher L (2003) Understanding temperature effects on PV system performance. In: Proceedings of the third world conference on photovoltaic energy conversion. Osaka, Japan, pp 2243–2246
91. Krauter SCW (2004) Development of an integrated solar home system. Sol Energy Mater Sol Cells 82:119–130
92. Franghiadakis Y, Tzanetakis P (2006) Explicit empirical relation for the monthly average cell-temperature performance ratio of photovoltaic arrays. Prog Photovolt Res Appl 14:541–551
93. Chenni R, Makhlouf M, Kerbache T, Bouzid A (2007) A detailed modelling method for photovoltaic cells. Energy 32:1724–1730
94. Durisch W, Bitnar B, Mayor JC, Kiess H, Lam KH, Close J (2007) Efficiency model for photovoltaic modules and demonstration of its application to energy yield estimation. Sol Energy Mater Sol Cells 91:79–84
95. Skoplaki E, Palyvos JA (2009) Operating temperature of photovoltaic modules: a survey of pertinent correlations. Renew Energy 34:23–29
96. Farr MG, Stein JS, Spatial variations in temperature across a photovoltaic array, proceeding to IEEE 40th Photovoltaic Specialist Conference (PVSC), 2014
97. Jones AD, Underwood CP (2001) A thermal model for photovoltaic systems. Sol Energy 70:349–359
98. Tsai HF, Tsai HL (2012) Implementation and verification of integrated thermal and electrical models for commercial PV modules. Sol Energy 86:654–665
99. Lobera DT (2014) Modeling and analysis of the operation of PV power generators under varying atmospheric conditions, Ph D. Thesis, Tampere University of Technology, Finland

100. Chow TT (2010) A review on photovoltaic/thermal hybrid solar technology. Appl Energy 87:365–379
101. Teo HG, Lee PS, Hawlader MNA (2012) An active cooling system for photovoltaic modules. Appl Energy 90:309–315
102. Sarhaddi F, Farahat S, Ajam H, Behzadmehr A, Adeli M (2010) An improved thermal and electrical model for a solar photovoltaic thermal (PV/T) air collector. Appl Energy 87:2328–2339
103. Joshi AS, Tiwari A, Tiwari GN, Dincer I, Reddy BV (2009) Performance evaluation of a hybrid photovoltaic thermal (PV/T) (glass-to-glass) system. Int J Therm Sci 48:154–164
104. Charalambous PG, Maidment GG, Kalogirou SA, Yiakoumetti K (2007) Photovoltaic thermal (PV/T) collectors: a review. Appl Therm Eng 27:275–286
105. Rosli MAM, Mat S, Anuar MK, Sopian K, Sulaiman MY, Ellias S (2014) Progress on flat-plate water based of photovoltaic thermal (PV/T) system: a review. Iranica J Energy Environ 5 (4):407–418
106. Krauter S (2004) Increased electrical yield via water flow over the front of photovoltaic panels. Sol Energy Mater Sol Cells 82:131–137
107. Odehand S, Behnia M (2009) Improving photovoltaic module efficiency using water cooling. Heat Transfer Eng 30(6):499–505
108. Liu L, Zhu L, Wang Y, Huang Q, Sun Y, Yin Z (2011) Heat dissipation performance of silicon solar cells by direct dielectric liquid immersion under intensified illuminations. Sol Energy 85:922–930
109. Yang DJ, Yuan ZF, Lee PH, Yin HM (2012) Simulation and experimental validation of heat transfer in a novel hybrid solar panel. Int J Heat Mass Transfer 55:1076–1082
110. Kerzmann T, Schaefer L (2012) System simulation of a linear concentrating photovoltaic system with an active cooling system. Renew Energy 41:254–261
111. Chandrasekar M, Suresh S, Senthilkumar T, Karthikeyan MG (2013) Passive cooling of standalone flat PV module with cotton wick structures. Energ Conver Manage 71:43–50
112. Kern EC Jr, Russell MC (1978) Combined photovoltaic and thermal hybrid collector systems, In: Proceedings of the 13th IEEE PV specialist conference, pp 1153–1157
113. Zhao X, Zhang X, Riffat SB, Su X (2011) Theoretical investigation of a novel PV/T roof module for heat pump operation. Energ Conver Manage 52:603–614
114. Zhang X, Zhao X, Smith S, Xub J, Yuc X (2012) Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies. Renew Sustain Energy Rev 16:599–617
115. Tang X, Zhao Y, Quan Z (2009) The experimental research of using novel flat-plate heat pipe for solar cells cooling, Proceeding to the Chinese thermal engineering physics of heat and mass transfer conference, pp 239–241
116. Zhao Y et al (2008) Photovoltaic cell radiating and combined heat and power system, Patent CN 200820123998 U
117. Feng QJ, Zhang MA, Dong L (2010) Analysis of a new photovoltaic thermal building integration system and correlative technology. Build Energy Environ 29(2):12–16
118. Amori KE, Al-Najar HMT (2012) Analysis of thermal and electrical performance of a hybrid (PV/T) air based solar collector for Iraq. Appl Energy 98(100):384–395
119. Al-Waeli AHA, Sopian K, Kazem HA, Chaichan MT (2017) PV/T (photovoltaic/thermal): status and future prospects. Renew Sustain Energy Rev 77:109–130
120. Al-Waeli AH, Sopian K, Kazem HA, Chaichan MT (2016) Photovoltaic solar thermal (PV/T) collectors past, present and future: a review. Int J Appl Eng Res 11(22):1075–10765
121. AHA A-W, Sopian K, Chaichan MT, Kazem HA, Hasan HA, Al-Shamani AN (2017) An experimental investigation on using of nano-SiC-water as base-fluid for photovoltaic thermal system. Energy Conserv Manage 142:547–558
122. Al-Waeli AHA, Chaichan MT, Kazem HA, Sopian K (2017) Comparative study to use nano-(Al2O3, CuO, and SiC) with water to enhance photovoltaic thermal PV/T collectors. Energ Conver Manage 148(15):963–973. https://doi.org/10.1016/j.enconman.2017.06.072

123. Al-Waeli AH, Sopian K, Chaichan MT, Kazem HA, Ibrahim A, Mat S, Ruslan MH (2017) Evaluation of the nanofluid and nano-PCM based photovoltaic thermal (PVT) system: an experimental study. Energ Conver Manage 151:693–708
124. Koehl M, Heck M, Wiesmeier S (2012) Modeling of conditions for accelerated life time testing of Humidity impact on PV-modules based on monitoring of climatic data. Sol Energy Mater Sol Cells 99:282–291
125. Elminir HK, Benda V, Tousek J (2001) Effects of solar irradiation conditions and other factors on the outdoor performance of photovoltaic modules. J Electr Eng 52(5–6):125–133
126. Kempe MD (2006) Modeling of rates of moisture ingress into photovoltaic modules. Sol Energy Mater Sol Cells 90(16):2720–2738
127. Park NC, Oh WW, Kim DH (2013) Effect of temperature and humidity on the degradation rate of multicrystalline silicon photovoltaic module. International Journal of Photo-energy 2013, Article ID 925280, 9 pages
128. Rotronic Instrument Corp., The Rotronic Humidity Handbook, All you never wanted to know about Humidity and didn't want to ask! 12/2005. www.rotronic-usa.com
129. Fanney AH, Davis MW, Dougherty BP, King DL, Boyson WE, Kratochvil JA (2006) Comparison of photovoltaic module performance measurements. Trans ASME 128:152–159
130. Morita K, Inoue T, Kato H, Tsuda I, Hishikawa Y, Degradation factor analysis of crystalline-Si PV modules through long-term field exposure test, in Proceedings of the 3rd World Conference on Photovoltaic Energy Conversion, pp 1948–1951, May 2003
131. Dhere NG, Raravikar NR (2001) Adhesional shear strength and surface analysis of a PV module deployed in harsh coastal climate. Sol Energy Mater Sol Cells 67(1–4):363–367
132. Han X, Wang Y, Zhu L, Xiang H, Zhang H (2012) Mechanism study of the electrical performance change of silicon concentrator solar cells immersed in de-ionized water. Energ Conver Manage 53(1):1–10
133. Bhattachary B, Dey S, Mustaphi B (2014) Some analytical studies on the performance of grid connected solar photovoltaic system with different parameters, proceeding to 3rd International Conference on Material Processing and Materials Science Characterization (ICMPC- 2014), vol 6, pp 1942–1950
134. Laronde R, Charki A, Bigaud D (2013) Lifetime estimation of a photovoltaic module subjected to corrosion due to damp heat testing. J Sol Energy Eng 135(2), Article ID 021010, 8 pages
135. Peike C, Hoffmann S, Hulsmann P (2013) Origin of dampheat induced cell degradation. Sol Energy Mater Sol Cells 116:49–54
136. Touati F, Massoud A, Abu Hamad J, Saeed SA, Effects of environmental and climatic conditions on PV efficiency in Qatar, International Conference on Renewable Energies and Power Quality (ICREPQ'13), Bilbao (Spain), 20–22 Mar 2013
137. Mekhilef S, Saidur R, Kamalisarvestani M (2012) Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. Renew Sustain Energy Rev 16:2920–2925
138. Gwandu BAL, Creasey DJ (1995) Humidity: a factor in the appropriate positioning of a photovoltaic power station. Renew Energy 6(3):313–316
139. Prakash JK, Gopinath N, Kirubakaran V (2014) Optimization of solar PV panel output: a viable and cost effective solotion, Int J Adv Technol Eng Res (IJATER) National Conference on "Renewable Energy Innovations for Rural Development" ISSN No: 2250–3536 20, New Delhi
140. Darwish ZA, Kazem HA, Sopian K, Alghoul MA, Chaichan MT (2013) Impact of some environmental variables with dust on solar photovoltaic (PV) performance: review and research status. Int J Energy Environ 7(4):152–159
141. Omubo-Pepple VB, Israel-Cookey C, Alamunokuma GI (2009) Effects of temperature, solar flux and relative humidity on the efficient conversion of solar energy to electricity. Eur J Sci Res 35:173–180

142. Katkar AA, Shinde NN, Koli GC, Gaikwad SP (2013) Evaluation of industrial solar cell w.r.t. temperature. Second International Conference on Emerging Trends in engineering (SICETE). IOSR J Mech Civ Eng (IOSR-JMCE) 3:27–38
143. Kazem HA, Chaichan MT, Al-Shezawi IM, Al-Saidi HS, Al-Rubkhi HS, Al-Sinani JK, Al-Waeli AHA (2012) Effect of humidity on the PV performance in Oman. Asian Trans Eng 2(4):29–32
144. Al Hanai T, Hashim RB, El Chaar L, Lamont LA (2011) Environmental effects on a grid connected 900 W photovoltaic thin-film amorphous silicon system. Renew Energy 36:2615–2622
145. Ettah EB, Udoimuk AP, Obiefuna JN, Opara FE (2012) The effect of relative humidity on the efficiency of solar panels in Calabar, Nigeria. Univ J Manag Soc Sci 2(3):8–11
146. Klampaftis E, McIntosh KR, Richards BS (2007) Degradation of an undiffused SI–SIO_2 interface due to humidity, 22nd European Photovoltaic Solar Energy Conference, 3–-7 September, Milan, Italy
147. Panjwani MK, Narejo GB (2014) Effect of humidity on the efficiency of solar cell (photovoltaic). Int J Eng Res Gen Sci 2(4)
148. Omubo-Pepple VB, Tamunobereton-ari I, Briggs-Kamara MA (2013) Influence of meteorological parameters on the efficiency of photovoltaic module in some cities in the Niger delta of Nigeria. J Asian Sci Res 3(1):107–113
149. Rachman A, Sopian K, Mat S, Yahya M (2011) Feasibility study and performance analysis of solar assisted desiccant cooling technology in hot and humid climate. Am J Environ Sci 7 (3):207–211
150. Chegaar M, Mialhe P (2008) Effect of atmospheric parameters on the silicon solar cells performance. J Electron Devices 6:173–176
151. Ndiaye A, Charki A, Kobi A, Ke´be´ CMF, Ndiaye PA, Sambou V (2013) Degradations of silicon photovoltaic modules: a literature review. Sol Energy 96:140–151
152. Kemp MD (2005) Control of moisture ingress into photovoltaic modules. In: 31st IEEE Photovoltaic Specialists Conference and Exhibition, Lake Buena Vista, Florida
153. Wohlgemuth JH, Kurtz S, Reliability testing beyond qualification as a key component in photovoltaic's progress toward grid parity, proceeding in IEEE International Reliability Physics Symposium Monterey, California, 10–14 Apr 2011
154. IEC: International Electro-technical Commission (1987) Standard IEC61215: crystalline silicon terrestrial photovoltaic (PV) modules. Design Qualification and Type Approval IEC Central Office, Geneva
155. Vazquez M, Ignacio RS (2008) Photovoltaic module reliability model based on field degradation studies. Progr Photovolt Res Appl 16:419–433
156. Quintana MA, King DL, McMahon TJ, Osterwald CR (2002.) Commonly observed degradation in field-aged photovoltaic modules. In: Proc. 29th IEEE Photovoltaic Specialists Conference, pp 1436–1439
157. Munoz MA, Alonso-Garcia MC, Nieves V, Chenlo F (2011) Early degradation of silicon PV modules and guaranty conditions. Sol Energy 85:2264–2274
158. Skoczek A, Sample T, Dunlop ED, Ossenbrink HA (2008) Electrical performance results from physical stress testing of commercial PV modules to the IEC61215 test sequence. Sol Energy Mater Sol Cells 92:1593–1604
159. Jansen KW, Delahoy AE (2003) A laboratory technique for the evaluation of electrochemical transparent conductive oxide delamination from glass substrates. Thin Solid Films 423:153–160
160. Oreski G, Wallner GM (2005) Aging mechanisms of polymeric films for PV encapsulation. Sol Energy 79:612–617
161. Oreski G, Wallner GM (2009) Evaluation of the aging behavior of ethylene copolymer films for solar applications under accelerated weathering conditions. Sol Energy 83:1040–1047
162. Kojima T, Yanagisawa T (2004) The evaluation of accelerated test for degradation a stacked a-Si solar cell and EVA films. Sol Energy Mater Sol Cells 81(1):119–123

163. Berman D, Faiman D (2007) EVA browning and the time-dependence of I-V curve parameters on PV modules with and without mirror enhancement in a desert environment. Sol Energy Mater Sol Cells 45(4):401–412
164. Wohlgemuth JH, Cunningham DW, Nguyen AM, Miller J (2005) Long term reliability of PV modules. In: Proc. 20th European Photovoltaic Solar Energy Conference, pp 1942–1946
165. Osterwald C R, Anderberg A, Rummel S, Ottoson L (2002) Degradation analysis of weathered crystalline-silicon PV modules. 29th IEEE Photovoltaic Specialists Conference, New Orleans, Louisiana
166. Wohlgemuth JH, Cunningham DW, Nguyen AM, Kelly G, Amin D (2010) Failure modes of crystalline silicon modules. In: Proceedings of PV module reliability workshop
167. Rueland E, Herguth A, Trummer A, Wansleben S, Fath P (2005) Optical l-crack detection in combination with stability testing for inline inspection of wafers and cells. In: Proceedings of 20th EUPVSEC, Barcelona, pp 3242–3245
168. Dallas W, Polupan O, Ostapenko S (2007) Resonance ultrasonic vibrations for crack detection in photovoltaic silicon wafers. Meas Sci Technol 18:852–858
169. Fesharaki VJ, Dehghani M, Fesharaki JJ, The effect of temperature on photovoltaic cell efficiency, in Proceedings of the 1st International Conference on Emerging Trends in Energy Conservation (ETEC ’11), Tehran, Iran, November 2011
170. Siddiqui R, Bajpai U (2012) Deviation in the performance of solar module under climatic parameter as ambient temperature and wind velocity in composite climate. Int J Renew Energy Res 2(3):486–490
171. Ettah EB, Eno EE, Udoimuk AB (2009) The effects of solar panel temperature on the power output efficiency Calabar, Nigeria. J Assoc Radiogr Niger 23:16–22
172. Hinds WC (1999) Aerosol technology: properties, behavior, and measurement of airborne particles. John Wiley & Sons, Inc., New York
173. Kaldellis JK, Kapsali M, Kavadias KA (2014) Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece. Renew Energy 66:612–624
174. Holmes JD (2001) Wind loading of structures. Spon Press, London
175. Tieleman HW Wind tunnel simulation of the turbulence in the surface layer. J Wind Eng Indus Aerodyn 36:1309–1318
176. Yorukoglu M, Celik AN (2006) A critical review on the estimation of daily global solar radiation from sunshine duration. Energ Conver Manage 47:2441–2450
177. Burdick J et al (1996) Qualification testing of thin-film and crystalline photovoltaic modules. Sol Energy Mater Sol Cells 41/42:575–586
178. Edwards B (1980) Collector deflections due to wind gusts and control scheme design. Sol Energy 25:231–234
179. Radu A, Axinte E, Theohari C (1986) Steady wind pressures on solar collectors on flat- roofed buildings. J Wind Eng Indus Aerodyn 23(1–3):249–258
180. Radu A, Axinte E (1989) Wind forces on structures supporting solar collectors. J Wind Eng Indus Aerodyn 32:93–100
181. Zhou Y, Kareem A (2002) Definition of wind profiles in ASCE 7. J Struct Eng 128 (8):1082–1086
182. National Research Council (2010) National building code of Canada, 13th edn. Associate Committee on the National Building Code, Ottawa
183. American Society of Civil Engineers (ASCE) (2005) Minimum design loads for buildings and other structures, ASCE 7-05. American Society of Civil Engineers, Reston
184. Miller R, Zimmerman D (1979) Wind loads on flat plate photovoltaic array fields. Phase III, Final report (No.DOE/JPL/954833813). Boeing Engineering and Construction Co., Seattle
185. Wood GS, Denoon RO, Kwok KC (2001) Wind loads on industrial solar panel arrays and supporting roof structure. Wind Struct 4(6):481–494
186. Kopp GA, Surry D, Chen K (2002) Wind loads on a solar array. Wind Struct 5(5):393–406

187. Bhattacharya T, Chakraborty AK, Pal K, Effects of ambient temperature and wind speed on performance of monocrystalline solar photovoltaic module in Tripura, India, Hindawi Publishing Corporation. Journal of Solar Energy 2014, Article ID 817078, 5 pages. https://doi.org/10.1155/2014/817078
188. Ladas DI, Stathopoulos T (2014) Wind effects on the performance of solar collectors on roofs, MSc Thesis, Concordia University, Montreal, Quebec, Canada
189. Vasan N, Stathopoulos T (2012) Wind tunnel assessment of the wind velocity distribution on vertical façades, Proceedings of eSim 2012: the Canadian Conference on Building Simulation, Page 61 of 614 May 1–4. Halifax Nova Scotia, Canada
190. Green MA, Emery K, Hishikawa Y, Warta W (2011) Solar cell efficiency tables (version 37). Progr Photovolt Res Appl 19:84–92
191. Rao A, Mani M (2013) Evaluating the nature and significance of ambient wind regimes on solar photovoltaic system performance, Building Simulation Applications BSA 2013, 1st IBPSA Italy conference, Bozen-Bolzano, pp 395–405
192. Matsukawa H, Kurokawa K (2005) Temperature fluctuation analysis of photovoltaic modules at short time interval. 31st IEEE Photovoltaic Specialists Conference, pp 1816–1819
193. Armstrong S, Hurley WG (2010) A thermal model for photovoltaic panels under varying atmospheric conditions. Appl Therm Eng 30:1488–1495
194. Schwingshackla C, Petittaa M, Wagnera JE, Belluardoc G, Moserc D, Castellia M, Zebischa M, Tetzlaff A (2013) Wind effect on PV module temperature: analysis of different techniques for an accurate estimation. Energy Procedia 40:77–86
195. Mattei M, Notton G, Cristofari G, Muselli M, Poggi P (2006) Calculation of the polycrystalline PV module temperature using a simple method of energy balance. Renew Energy 31:553–567
196. Skoplaki E, Boudouvis AG, Palyvos JA (2008) A simple correlation for the operating temperature of photovoltaic modules of arbitrary mounting. Sol Energ Mat Sol C 92:1393–1402
197. Koehl M, Heck M, Wiesmeier S, Wirth J (2011) Modeling of the nominal operating cell temperature based on outdoor weathering. Sol Energ Mat Sol C 95:1638–1646
198. Kurtz S, Whitfield K, Miller D, Joyce J, Wohlgemuth J, Kempe M et al (2009) Evaluation of high-temperature exposure of rackmounted photovoltaic modules. 34th IEEE Photovoltaic Specialists Conference (PVSC), pp 2399–2404
199. Chen H, Chen X, Li S, Ding H (2014) Numerical study on the electrical performance of photovoltaic panel with passive cooling of natural ventilation. Int J Smart Grid and Clean Energy 4(4):395–400
200. Trinuruk P, Sorapipatana C, Chenvidhya D (2007) Effects of air gap spacing between a photovoltaic panel and building envelope on electricity generation and heat gains through a building. Asian J Energy Environ 8(1 and 2):73–95
201. Geurts CPW, Steenbergen RDJM (2009) Full scale measurements of wind loads on stand-off photovoltaic systems. 5th European & African Conference on Wind Engineering (EACWE), Florence, Italy
202. Velicu R, Moldovean G, Scaletchi I, Butuc BR (2010) Wind loads on an azimuthal photovoltaic platform. Experimental study. In: Proceeding of International Conference on Renewable Energies and Power Quality, Granada, Spain
203. Shademan M, Barron RM, Balachandar R, Hangan H (2014) Numerical simulation of wind loading on ground-mounted solar panels at different flow configurations. Can J Civ Eng 41:728–738
204. Ogedengbe AA, Hangan H, Siddiqui K (2015) Experimental investigation of wind effects on a standalone photovoltaic (PV) module. Renew Energy 78:657–665
205. Goossens D, Van Kerschaever E (1999) Aeolian dust deposition on photovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance. Sol Energy 66(4):277–289
206. U.S. Energy Information Administration, International Energy Statistics—Total Electricity Installed Capacity, Aug 2010

207. Bony L, Doig S, Hart C, Maurer E, Newman S (2010) Achieving low-cost solar PV: Industry workshop recommendations for near-term balance of system cost reductions, Opportunity 1: efficient design for wind forces, Rocky Mountain Institute, RMI.org
208. Li H, Ma W, Wang X, Lian Y (2011) Estimating monthly average daily diffuse solar radiation with multiple predictors: a case study. Renew Energy 36:1944–1948
209. Gueymard CA (2009) Direct and indirect uncertainties in the prediction of tilted irradiance for solar engineering applications. Sol Energy 83(3):432–444
210. Kudish AI, Evseev EG (2010) The analysis of solar UVB radiation as a function of solar global radiation, ozone layer thickness and aerosol optical density. Renew Energy 52(1):31–42
211. Chaichan MT, Kazem HA, Kazem AA, Abaas Kh I, Al-Asadi KAH (2015) The effect of environmental conditions on concentrated solar system in desertic weathers, International. J Sci Eng Res 6(5):850–856
212. Kazem HA, Chaichan MT, Saif SA, Dawood AA, Salim SA, Rashid AA, Alwaeli AA (2015) Experimental investigation of dust type effect on photovoltaic systems in north region, Oman. Int J Sci Eng Res 6(7):293–298
213. Eliminir HK, Ghitas AE, Hamid RH, Hussainy FE, Beheary MM, Abdel-Moneim KM (2006) Effect of dust on the transparent cover of solar collectors. Energ Conver Manage 47:3192–3203
214. Jiang H, Lu L, Sun K (2011) Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules. Atmos Environ 45:4299–4304
215. Peel MC, Finlayson BL, McMahon TA (2007) Updated world map of the Köppen- Geiger climate classification. Hydrol Earth Syst Sci 11:1633–1644
216. Goosens D, Kerschaever EV (1999) Aeolian dust deposition on photovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance. Sol Energy 66:277–289
217. Mani M, Pillai R (2010) Impact of dust on solar photovoltaic (PV) performance: research status, challenges and recommendations. Renew Sustain Energy Rev 14:3124–3131
218. Hottel H, Woertz B (1942) Performance of flat-plate solar-heat collectors. Trans Am Soc Mech Eng (USA) 64:91–104
219. Nimmo B, Said SAM (1979) Effects of dust on the performance of thermal and photovoltaic flat plate collectors in Saudi Arabia—preliminary results. In: Vezirogluv TN (ed) Proceedings of the 2nd Miami International Conference on Alternative Energy Sources, Dec 10–13. pp 223–238
220. Salim A, Huraib F, Eugenio N (1988) PV power-study of system options and optimization. In: Proceedings of the 8th European PV solar energy conference
221. Maghrabi A, Alharbi B, Tapper N, Impact of the March 2009 dust event in 1 Saudi Arabia on aerosol optical properties, meteorological parameters, sky temperature and emissivity
222. Wakim F (1981) Introduction of PV power generation to Kuwait. Kuwait Institute for Scientific Researchers, Report No. 440
223. Sayigh AAM (960) Effect of dust on flat plate collectors. In: de Winter F, Cox M (eds) Sun: mankind's future source of energy; proceedings of the international solar energy congress, New Delhi, vol 2. Pergamon Press, New York, pp 964–1978
224. Sayigh AAM, Al-Jandal S, Ahmed H (1985) Dust effect on solar flat surfaces devices in Kuwait. Proceedings of the workshop on the physics of non-conventional energy sources and materials science for energy. ICTP, Triest, pp 353–367
225. Qasem H, Betts TR, Müllejans H, AlBusairi H, Gottschalg R (2014) Dust-induced shading on photovoltaic modules. Prog Photovolt Res Appl 22:218–226
226. Touati F, Al-Hitmi M, Bouchech H, "Towards understanding the effects of climatic and environmental factors on solar PV performance in Arid Desert Regions (Qatar) for various PV technologies". World Renewable Energy Congress, Indonesia, International Conference on Renewable Energy and Energy Efficiency, 17–19 Oct 2011, Bali, Indonesia

227. Darwish ZA, Kazem HA, Sopian K, Al-Goul MA, Alawadhi H (2015) Effect of dust pollutant type on photovoltaic performance. Renew Sustain Energy Rev 41:735–744
228. Kazem HA, Khatib T, Sopian K, Buttinger F, Elmenreich W, Albusaidi AS (2013) Effect of dust deposition on the performance of multi-crystalline photovoltaic modules based on experimental measurements. Int J Renew Energy Res 3(4):850–853
229. Sukhatme SP (2003) Solar energy: principles of thermal collection and storage. Tata McGraw-Hill, New Delhi
230. Nahar N, Gupta J (1990) Effect of dust on transmittance of glazing materials for solar collectors under arid zone conditions of India. Solar Wind Technol 7:237–243
231. Sayyah A, Stark J, Abuhamed T, Weisinger W, Horenstein M, Mazumder MK, Energy yield loss caused by dust deposition in solar power plants, Proc. 2012 Joint Electrostatics Conference
232. UN Public Information Office (UNPIO) 2013. www.iq.one.un.org. Accessed on May 2013
233. Brown LR (2011) World on the edge: how to prevent environmental and economic collapse. Earth Policy Institute, USA
234. Crook J, Climate analysis and long range forecasting of dust storms in Iraq, M.Sc thesis applied to Naval Postgraduate School in June 2009
235. Public Information Office (UNPIO), UN Envoy Supports Greenbelts in Iraq to Combat Sandstorms, Baghdad, 23 Feb 2013
236. US Ministry of Water Resources (USMWR) (2005) Iraq Reconstruction–Water Resources Sector, Speech by the Minister of Water Resources in USA
237. Fadhil AM (2009) Land degradation detection using geo-information technology for some sites in Iraq. J Al-Nahrain Univ 12(3):94–108
238. Pease P, Vatche P, Tchakerian N, Tindale N (1998) Aerosols over the Arabian Sea: geochemistry and source areas for aeolian desert dust. J Arid Environ 39:477–496
239. Xin-jiang Z, Cheng L, Xiao-ping X et al (1995) Cloudiness features of two kinds of dust devil weather in China. J Meteorol 21(2):27–31
240. Wilkerson WD (1991) Dust and sand forecasting in Iraq and adjoining countries, AWS/TN—91/001, Air Weather Service, Scott AFB, IL, p 63
241. McDonald E, Caldwell T Geochemical and physical characteristics of Iraqi dust and soil samples, Final Project Report, Yuma Proving Ground Natural Environments Test Office, 8 Oct 2004
242. ASTM (American Society for Testing and Materials) (2000) Standard test method for determining the particle size distribution of alumina quartz by laser light scattering, C 1070-86 (reapproved 1992), 2000 Annual Book of ASTM Standards, vol 15, no 2, ASTM, Philadelphia, PA, pp 375–376
243. Gee GW, Or D (2002) Particle-size analysis. In: Dane JH, Topp GC (eds) Methods of soil analysis: part 4–physical methods. No. 5, Soil Sci. Soc. Am. Book Series, Soil Science Society of America, Madison, pp 255–293
244. Anderson J (2004) An analysis of a dust storm impacting operation Iraqi Freedom, 25–27 March 2003, MSc Thesis, Dept of Meteorology, Naval Postgraduate School, p 123
245. Nelson DW, Sommers LE (1996) Total carbon, organic carbon and organic matter. In: Sparks DL et al (eds) Methods of soil analysis: part 3– chemical methods. No. 5, Soil Sci. Soc. Am. Book Series, Soil Science Society of America and American Society of Agronomy, Madison, pp 961–1010
246. Karathanasis AD, Hajek BV (1996) Elemental analysis by X-ray fluorescence spectroscopy. In: Sparks DL et al (eds) Methods of soil analysis: part 3–chemical methods. No. 5, Soil Sci. Soc. Am. Book Series, Soil Science Society of America and American Society of Agronomy, Madison, pp 161–223
247. Akhter MS, Madany IM (1993) Heavy metals in street and house dust in Bahrain. Water Air Soil Pollut 66:111–119
248. Draxler RR, Gillette DA, Kirkpatrick JS, Heller J (2001) Estimating PM_{10} air concentrations from dust storms in Iraq, Kuwait and Saudi Arabia. Atmos Environ 35:4315–4330

249. Al-Kharouf SJ, Al-Hamarneh IF, Dababneh M (2008) Natural radioactivity, dose assessment and uranium uptake by agricultural crops at Khan Al-Zabeeb, Jordan. J Environ Radioact 102 (11):975–1064
250. Landis GA (1997) Mars dust removal technology, NASA Lewis Research center. IEEE, Energy Convers Eng Conf 1:764–767
251. Alwan AA (2012) The effect of dust storms on total solar radiation rates for Baghdad City, Iraqi Information Agency (IIA)
252. Al-Rasoul KT, Ali FH, Ali MM, Al-Shakry AJ (2010) Characterization of quartz and calcite particle size presents in local dust fell on Baghdad on June 2009, Iraqi. J Phys 8(12):60–64
253. Ferg EE, Loyson P, Gromer G (2008) The influence of particle size and composition on the quantification of Airborne Quartz analysis on filter paper. Ind Health 46:144–151
254. Wang AS, Angel SJ, Chaney RL, Delorme TA, Reeves RD (2006) Soil PH effects on uptake of CD and Zn by Thlaspi caerulescene. Plant and Soil 281:325–337
255. Lee CJ, Zhang SC, JudithX Y, Chow C, An ZS, Ho KF, Watson JG, Fung K, Wang YQ, Shen ZX (2005) Characteraztion of airborne carbonate over a site near Asia dust soure region during spring 2002 and its climatic and environmental significance. J Geophys Res 110: D03203
256. Sims RA, Biris AS, Wilson JD, Yurteri CU, Mazumder MK, Calle CI, Buhler CR (2002) Development of transport self-cleaning dust shield for solar panels. Proc. ESA-IEEE Joint Meeting on Electrostatics, Little Rock, pp 814–821
257. Kasim KN, Al-Wattar AJ, Abbas KK (2010) New technique for treatment of the dust accumulation from PV solar panels surface, Iraqi. J Phys 8(12):54–59
258. Al-Sudany AHS (2009) Studying the effects of dust and temperature on the solar cell performance, M.Sc Thesis, Al-Mustansiriyah University
259. Astaw KS (2007) Tropical Area is a best place to achieve the best performance of amorphous silicon photovoltaic**,** electronic and electrical engineering, Loughborough University, Leicestershire, LE113TU, UK, TPSDP Research Fellowship (TPSDP-ADB) No.1792-INO
260. David LK (1997) Photovoltaic module and array performance characterization methods for all system operating conditions, Sandia National Laboratories, Photovoltaic Systems Department, MSO 752, Albuquerque, NM 87185, New York, pp 1–22
261. Chaichan MT, Mohammed BA, Kazem HA (2015) Effect of pollution and cleaning on photovoltaic performance based on experimental study. Int J Sci Eng Res 6(4):594–601

Chapter 6
Photovoltaic Experiences in Iraq Neighborhood Countries

6.1 Iran

Iran, Iraq's neighbor to the east, has very old historic roots. Iran is characterized by the importance of its geopolitical location as a meeting point for three Asian destinations (West, Central, and Southern Asia). Iran overlooks the Caspian Sea to the north, and the Arabian Gulf and Gulf of Oman to the south. Tehran is the political, cultural, and commercial center, capital, and the largest city in the country. Iran is a regional power [1, 2] and an important partner in international energy security and the global economy because Iran has the second-largest reserves of natural gas in the world and the fourth largest proven oil reserves [3].

Iran is the 18th largest state in the world in terms of area, 1,648,195 km^2 [3]. Its area equals that of the UK, France, Spain, and Germany combined. Iran is located between the latitudes 24–40° north of the equator, and between the longitudes 44–64° east of Greenwich, and has a 1,458 km border with Iraq to the west.

Iran consists of a plateau except for the coast of the Caspian Sea and the province of Khuzestan. It is one of the most mountainous countries in the world; the rugged mountain landscape is dominated by different ranges that separate basins or plateaus from each other. The west (including the Caucasus, Zagros, and Alborz mountains) has the highest point in Iran, Mount Damavand at 5,610 m [4].

The dense rainforests called Shomal, or the jungles of Iran, cover the north. The east consists mostly of desert basins such as the Dasht-e Kavir, the largest desert in Iran in the central northern part of the country. Dasht Lut is located in the east, as are some salt lakes. Wide plains are found along the Caspian coast and the northern tip of the Persian Gulf, where Iran is located on the borders of the mouth of the Shatt al-Arab River. The plains spread over the remaining length of the coast along the Arabian Gulf, the Strait of Hormuz, and the Gulf of Oman.

Iran's climate ranges between arid or semi-arid to subtropical along the Caspian Sea and North Coast forests. On the northern edge of the country (the Caspian coastal plain) the temperatures rarely drop below zero, for the rest of the region is

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still wet. Summer temperatures rarely exceed 29 °C [4, 5]. Annual rainfall is 680 mm in the east. The rain in the western parts of the plain is more than 1,700 mm per year. The temperature in the Zagros Basin is low, with temperatures being very cold in the winter, to below zero, and snow falling on a daily basis. The eastern and central basins and the deserts are arid areas, with less than 200 mm of rain [6]. The average summer temperatures exceed 38 °C. The Arabian Gulf and the Gulf of Oman coastal plains in southern Iran have a mild winter and a wet and very hot summer. The annual rainfall ranges from 135 to 355 mm [7]. Iran is a hot and dry geographical area with about 63–98% sunny days across Iran. Figure 6.1 shows the amount of sun energy received in variable areas of the country [8].

Iran has enormous potential to generate solar energy and also owns vast tracts of land that can be used as solar stations. The solar power plant needs flat land with a slope of less than 1% without vegetation cover, which is largely available in Iran. Other

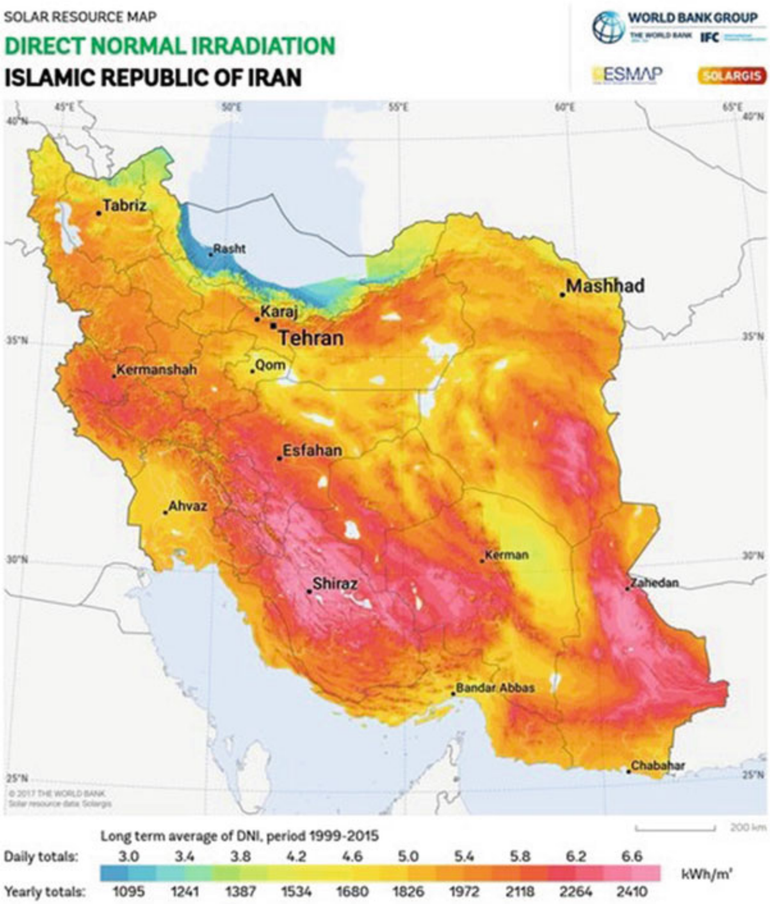

Fig. 6.1 Map of the average received energy in Iran

techniques include dish engine systems and photovoltaics (PVs) on sloping lands. The PV plants do not need to provide water and can operate remote vast land in Iran.

Researchers in Iranian research centers and universities determined the main differences in the sun's rays for the total area of Iran. The direct natural radiation areas in the tropics and clear sky areas were also determined, which are located in areas with latitudes of 15–40° north or south. Figure 6.1 shows the solar intensity map of Iran.

Currently, Iran has the fourth largest reserves of oil and gas in the world [9, 10] and is the second largest oil exporter [11, 12]. In 2005, the average daily oil production in Iran was four million barrels (640,000 m^3/d), compared with a peak of six million barrels per day reached in 1974. Due to the economic blockade in the early years of the twentieth century, the efficiency of industrial infrastructure was decreased. In 2005, Iran managed to drill new exploratory wells, which increased the production rates.

Until the year 2004, a large proportion of natural gas reserves in Iran were untapped. Today, Iran has become the third country in the world with GTL conversion technology, which was developed locally [13]. In addition, the new conventional hydroelectric stations and the simplification of coal-fired and oil-fired power plants installed to 33,000 MW. From this amount, about 75% of the station was fueled with natural gas, 18% oil, and 7% on hydroelectric power. In 2004, Iran opened its first terrestrial wind power and thermal energy-powered stations while the first solar thermal power plant was opened in 2009.

The demographic expansion and acceleration of manufacturing operations intensified the demand for electricity, which grew by 8% per annum. The government's goal of 53,000 megawatts of installed capacity by 2010 was reached by combining the new line of work stations with gas and by adding hydroelectric and nuclear energy power generation. Iran established its first nuclear power plant at Bushehr in 2011 [14, 15].

Iran occupies the 16th place among world nations in generating electricity with 68,606 MW generated in the country. Iranian government agencies have shown that the level of export of electricity rose to 10 MW compared with the previous year, which was 6.8 MW. The proportion of the export of electricity to Iran's neighbors has risen to 4.149 MW, an increase of 40% compared to the same period in 2011, where the size of Iran's exports was 2.853 MW [16].

The process of exporting electricity is stopped during the summer due to the rise in local consumption. It resumes exporting electricity to neighboring countries during the remaining months of the year. The proportion of electricity consumption in Iran has fallen to coincide with the implementation of the law of the rationalization of government support, providing the ground for increasing the size of the export of electricity to the importing countries. Iran exchanges energy with Armenia, Pakistan, Turkmenistan, Turkey, Azerbaijan, Iraq, and Afghanistan.

The Iranian energy system suffers from several developments:

- The transport sector has expanded rapidly with urban personal transport, excessive energy share, and a long-distance transport that result in high pollution levels.

- The residential sector takes a high share of the electricity consumption.
- The subsidization and low prices of energy such as electricity, gasoline, and oil accompanied with high energy consumption rates [17].

Motavaselian [18] declared that Iran suffers from transmitting electricity loss, which reaches about 29% of the total annual produced capacity of 56,200 MW. The electricity production industry is ruled by government in Iran, and its development was slow and not very efficient. Starting from 2011, a new energy plan was implemented by the Iranian government. The 5-year plan set its sights on modifying energy prices to reach those of world energy prices. The electricity was to be sold without subsidy and with the average electricity production cost. The plan takes in the privatization of the power market, and increases the share of renewable energy resources in generated electricity [19].

In Iran, the residential sector has a large share of the total electricity consumption; and a large part of the lost energy occurs because of weakly designed and old constructed buildings accompanied by the use of inefficient appliances. In general, to succeed the utilization of renewable energies, the energy consumption intensity must be decreased to its minimum value. The renewable energy systems have lower energy intensity compared to traditional energy sources.

The electricity grid spreads widely into almost all urban areas of Iran and a high percentage of the electricity consumption comes from urban areas [20]. Iranian researchers have noticed that there are many difficulties with using PV systems in the residential sector due to the quandaries encountered in mismatching the production and consumption. Most of the PV system electricity production occurs during daytime, while the peak electricity consumption in the residential sector occurs at night due to the use of lights and the operation of various appliances. The PV module efficiency depends totally on the solar incidence, which requires additional costs in order to track the sun. So, to ensure the distribution and dissemination of PV modules in the residential sector its costs must reduce to about 50% of currently occurring costs [21].

Iran has many renewable energy sources which can be summarized as [22]:

- Hydropower

Hydropower is a significant Iranian renewable energy resource with electrical production of about 7,422.5 MW.

- Wind energy

Wind is considered as the second source of renewable energy as Iran has average wind speed of 6 m/s in some parts and there are other areas with high wind speeds. Iran has announced that the largest wind plant in the country will be launched in the Iranian city of Mengele in the coming months of 2016 to produce electricity as shown in Fig. 6.2. This plant produces 180,000 MW per year, which will be a part of the total 300,000 MW/year of electricity produced from renewable energies in various stations throughout Iran [23].

Fig. 6.2 Mengele wind station

Also, the electricity production in the Bushehr nuclear plant increased, which has been linked to the national electricity grid in the last month, with a capacity of 60 MW, which will be increased to 450 MW bringing it to 50% of its maximum capacity. It is expected that the plant's electricity production may be as high as a thousand megawatts when fully operational in late 2016 [24, 25].

The generated wind power was about 140 million kWh, and there is a new governmental policy to enter the private sector in this field.

- Geothermal

There are some programs to exploit this potential. To date, two governmental geothermal plant activities have been implemented. About 60% of the Meshkin-Shahr station has been established. The planned capacity of this station is 370 million kW per year. The second project is the 3–5 MW plant Ardebil, which is about 30% complete.

- Fuel cell

The Iranian authorities started with installing and operating a 25 kW polymeric fuel cell. There is an intention to enhance the local technical knowledge by designing and manufacturing a 5 kg polymeric fuel cell for research purposes [26].

- Biomass

Several studies were conducted on biogas production in Saveh city to produce about 600 kW. Studies were carried out in Mashhad city and Shiraz where a biomass power plant produces about 650 kW and 1,060 kW respectively [26].

- Solar energy

Iran is located on the Sunbelt and has 2800 sun hours per year. The solar insulation average for Iran is estimated at 2000 kWh/m2 year according to Ref. [27]. Iran has the advantages of location and solar intensity rate to best utilize solar energy. The base installed PV electricity generation systems capacity, in Iran, is 175 kW. Iran has installed about 77,000 m2 of solar collectors before 2006 [26]. Many projects began to be implemented in the application of solar thermal systems, such as:

1. The Damghan Project, which was started in 1994 to provide part of the electricity requirements to Hassinan and Moalleman villages, about 120 km of southern Damghan with a capacity of 97 kW. The aim of this project was to compensate the electricity shortage in these two villages [28].
2. Gazik boarder point project (1996): The Gazik border area is over 50 km away from the electrical grid. A standalone PV power plant was used to provide electricity for this outpost. The use of solar PV power reduced the demand for fuel supplies, preventing the long distance extension of the national grid . Also, this technology does not require maintenance efforts [29]. For all these, this experiment was very successful.
3. The Karaj Dam PV module project established in 1997, which aimed to provide the required day and night illumination for tunnel No. 6 of Karaj-Chalus road independent of the electricity grid [30].
4. The Ardakan Village Solar Bath Unit was established in 1999 to equip a pump bath unit. The system included 120 collectors, two 3,000 L tanks, two circulating pumps, two expanding reservoirs with a capacity of 150 L each, and 340 L of antifreeze. The unit area was 650 m^2. The most important benefit of this project was the fuel disbursements reduction in addition to normalizing solar bath use [31].
5. Taleghan Photovoltaic Power Plant was established in 2000 with a capacity of 30 kW. The nominal installed equipment capacity is 40 kW and can be increased to 100 kW. The system is connected to the electricity grid. The useful life of the plant is estimated to be 25 years and is located in an area with an average annual sunlight of 2,700 h. The aim of this project was to support the national grid with electricity and the growing power requirements of the region [27].
6. The construction of the Shiraz solar thermal power plant (first phase) with a capacity of 250 kW. This project is considered to be one of the most important projects in renewable energy in in Iran.
7. The installation of 18,000 solar water heaters for household and office utilization [26].

As mentioned above, the Iranian government has a trend of increasing the share of renewable energy from total generated electricity, especially solar energy.

Many researchers studied the effect of air pollution on the PV module performance. The studies revealed a large effect of air pollution on PV performance, where the air pollution reduced the PV output by 60% on some polluted winter days.

Reference [32] showed the severity of air pollution in Tehran, where the modules performance reduced from 45 W to 17 W during the test period. The reduction in the PV yield due to air pollution is significant in Iranian cities.

6.2 Turkey

Turkey is Iraq's northern neighbor; it is a secular democratic state located on the Bosphorus and Dardanelles straits, which together enclose the Sea of Marmara. Turkey links the Black Sea to the Aegean Sea and Asia to Europe. Turkey is located between the latitudes 35° and 43° north, and longitudes 25° and 45° east. Turkey is the 37th largest country in the world in terms of area. The country is surrounded by the sea on three sides: the Aegean Sea to the west, the Black Sea in the north and the Mediterranean Sea to the south. Also, it is bordered by the Marmara Sea in the north-west of the country [33].

Turkey's climate varies from one place to another. The coastal areas of Turkey bordering the Aegean Sea and the Mediterranean Sea have a moderate Mediterranean climate, with hot, dry summers and winters ranging from mild to cold and wet. The coastal regions of Turkey by the Black Sea are characterized by warm and humid summers and cool, wet winters. The greatest amount of rain on the Turkish coasts falls at the Black Sea coast region in Turkey, which is characterized by a high incidence of torrential rain. The climate of the coastal areas of Turkey bordering the Sea of Marmara (including Istanbul), which connect the Aegean and the Black Seas, is characterized by the transition from the mild Mediterranean climate, its summer is hot and dry and its winters are cold and mild to cold and wet. In the West, an average temperature of less than 1 °C in winter is achieved. Summer is hot and dry, with temperatures above 30 °C and the annual rates of precipitation are about 400 mm [34, 35].

The population of Turkey is 70,586,256, according to the last official census in 2007 [36]. About three-quarters of the population live close to towns and cities. The population is increasing by 1.5% annually, according to estimates up to the year 2009. The average population density in the country is up to 92 people per square kilometer [37].

The industry and trade centers are concentrated around the city of Istanbul and in the rest of the major cities, especially in the west. There is a big difference in the standard of living and economic situation between the industrialized west and the agricultural east. The agricultural sector is the largest sector in terms of employment, with about 40% of the total work force of the country, but it provides only about 12% of national output. The industrial sector produces about 29.5% of the gross national product of Turkey and the service sector about 58.5% [38].

The most important industries in Turkey are textiles, food and beverages, electrical appliances, automobiles, chemicals, and leather. The plastic strip makes up 28% of Turkish exports. The most important mineral resources located on Turkish territory are coal, charcoal, iron, lead, zinc, copper, and silver. Turkey is also one of the largest producers of chrome in the world. There is a small oil reserve in the southeast of the country [39].

Table 6.1 Energy in Turkey

	Capita (million)	Prim. energy (TWh)	Production (TWh)	Import (TWh)	Electricity (TWh)	CO2-emissions Mt
2004	71.79	952	280	677	127	209
2007	73.9	1,163	317	881	163	265
2008	71.08	1,146	337	843	171	264
2009	71.9	1,136	352	817	165	256
2012	74.9	1,360	355	1,035	207	302
2013	75.77	1,355	376	1,008	209	384
Change 2004–2009	0.2%	19.2%	25.6	20.7%	30.2%	22.4%

Cotton, tea, tobacco, olives, grapes, citrus, fruit, vegetables, grain, and barley are the most important agricultural crops in the country. Turkey is one of the largest producers of hazelnuts in the world. Turkey has the seventh most warm groundwater in the world and the most in Europe. Turkey is considered to be the seventh country with regard to global cultivation [40].

Turkey imports most of its energy. Turkey is strategically positioned between two continents with 65% of the energy resources in the east of the country, while 65% of the demand is in the west [41]. Turkey produces a lot of lignite. "Lignite power stations churn out large amounts of carbon dioxide, with a comparably low level of efficiency" [42]. New coal-fired power stations are being built despite the environmental impact of the coal industry. Currently most gas comes from Russia via the Blue Stream pipeline because Iranian gas, which comes through the Tabriz–Ankara pipeline, is more expensive (as of the first quarter of 2014). Azerbaijan supplies Turkey through the South Caucasus Pipeline and may supply more in the future through the Trans-Anatolian gas pipeline, which is currently under construction. Iraq may also supply gas in the future, through the Southern Gas Corridor [43]. Also, some gas is imported as LNG. At the moment, only a small proportion of gas imports are re-exported to the EU. Table 6.1 illustrates the energy situation in Turkey [44].

6.2.1 Energy Situation in Turkey

Fossil fuels such as natural gas, coal, and oil represent approximately 90% of the total primary energy supply in Turkey. They cover 73.5% of the electricity supply with the rest supplied through renewable energy sources; 92.8% of renewable energy is produced from hydropower, and about 7% from wind, geothermal, biomass, and recently solar energy [45, 46].

Turkey's oil consumption in 1970 reached up to 19 million tons, and rose in 2010 to 105 million tons. It is expected that the oil consumption will rise up to 222.4 million tons in 2020. At the same time, renewable energy's share of primary energy consumption has steadily declined, starting in 1980. The share of renewable energies

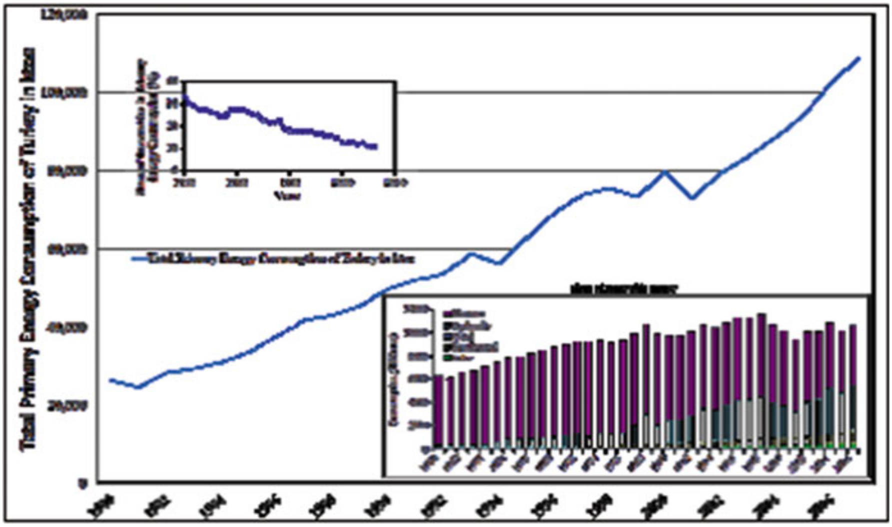

Fig. 6.3 Turkey's primary energy consumption 1970–2006, and the share of renewable energy

in 1970 was about 35% of the total energy consumed, but in 2010 fell to about 10% [49]. The most important renewable energy used in Turkey today is biomass, while in recent years it was hydropower. Most of the fossil fuel consumption is covered (whether natural gas, oil, or coal) through import, making the Turkish economy heavily dependent on imported energy sources from foreign countries [50].

The turn towards the use of natural gas for the production of electricity in Turkey was dramatic, quickly making it the main contributor to the electricity supply. According to Fig. 6.3, Turkey imported an average of 95.7% of the used natural gas in the years 1988–2003 [51].

Figure 6.3 shows the evolution of the distribution of fuel in the years 1940–2009. As can be seen in the graph, coal covered about 86% of the energy demand in 1940. The rest of the demand was covered by the renewable energies (8% mostly hydropower) and natural gas (6%). Over the years, a continuous increase in the use of natural gas has occurred, especially after 1990. The increasing use of imported natural gas changed the situation, leading to a fuel distribution of 19% renewable natural, 52% gas, and 29% coal in 2009 [48].

6.2.2 Renewable Energies in Turkey

- Geothermal Energy

In 1965, the Turkish Mineral Research and Exploration Co., which is owned by the state, began with the first geological and geophysical surveys in south western Turkey. In 1968, the Kızıldere geothermal reservoir, a field on the western branch

Table 6.2 Turkey's geothermal power plants

Station	Capacity (MW)	Community	Status	Construction year
Kizildere	95	Saraykoy, Denizli	Operational	1984
Gumuskoy	13.2	Germencik, Aydin	Operational	1992

of Büyük Menderes Graben, was discovered as a geothermal field suitable for electricity generation. The first power plant was built as a prototype facility in 1974 with 500 kW installed capacity. The generated electricity was distributed to the households in the vicinity free of charge. The state-owned Elektrik Üretim A.Ş. (EÜAŞ) enlarged the installed capacity up to 17.4 MW in 1984. However, the average actual power was around 10 MW. In 2008, the power plant was transferred to a private company called Zorlu Energy in the frame of privatization. Zorlu Energy obtained the right of operating lease for 30 years, and increased the capacity from 6 MW to 15 MW within a short time. In December 2013, the Kızıldere Geothermal Power Plant reached an installed capacity of 95 MW, making it Turkey's biggest [52, 53].

As of 2005, Turkey had the fifth highest direct usage and capacity of geothermal energy in the world. Turkey's capacity as of 2005 is 1,495 MW with a usage of 24,839.9 TJ/year or 6,900.5 GWh/year at a capacity factor of 0.53. Most of this is in the form of direct-use heating however geothermal electricity is currently produced at the Kizildere plant in the province of Denizli producing 120,000 tons of liquid carbon dioxide and dry ice. As of 2006 and 2010, there were two plants in Aydın generating 8.5 and 11.5 MW, respectively [54].

Direct-use heating has been mostly district heating serving 103,000 residences (827 MW and 7712.7 TJ/year). There is also individual space heating (74 MW and 816.8 TJ/year); 800,000 m^2 of heated greenhouses (192 MW and 3,633 TJ/year); and 215 balneological facilities, 54 spas and bathing and swimming pools (402 MW and 12,677.4 TJ/year) [38]. It has been reported that at least 1.5 million houses, currently heated by natural gas, can switch to being heated by thermal water [55].

As of 2005, 170 future geothermal prospects had been identified, with 95% in the low-to-medium enthalpy range suitable for direct-use applications [56]. In 2010 the installed geothermal electricity generation capacity was 100 MWe while direct use installations were approximately 795 MWt [57] (Table 6.2).

- Hydropower in Turkey

Turkey's dependence on imported fossil fuels has been accompanied by continued growth for electricity, which has recently reached around 7% per year. This situation led the country to move increasingly toward developing the locally available resources to meet demand. Turkey is helped by the appropriate geographical presence of large areas that can provide hydroelectric power such as the existence of areas with an average altitude of 1,100 m above sea level in the Euphrates and Tigris basin. Also, there are potential and ample areas available for the development of this energy, such as the Black and the Mediterranean Sea coast, and the eastern regions of

Table 6.3 Turkey hydroelectric power stations

Station	Capacity (MW)	Community	Status	Construction year
Altinkaya Dam	700	Kizilirmak	Operational	
Aslntas Dam	138	Ugurla	Operational	
Ataturk Dam	2400	Eskin	Operational	1982
Batman Dam	198	Catakkapora	Operational	
Berke Dam	510	Duzici, Osmanyle	Operational	
Birecik Dam	672	Bilkes	Operational	
Borcka Dam	300	Borcka, Artivin	Operational	
Boyabat Dam	513	Boyabat	Operational	2012
Catalan Dam	169	Adana	Operational	
Deriner Dam	670	Artivin	Operational	2012
Devecikonagi Dam	29	Bursa	Operational	2012
Dicle Dam	110	Altaykoy	Operational	
Gezende Dam	159		Operational	
Gokcekaya Dam	300	Cokcekaya	Operational	
Hasam Ugurlu Dam	500	Ugurlu	Operational	
Hirfnali Dam	128	Hirfanlar	Operational	
Illisu Dam	1200		Under construction	2015
Karakaya Dam	1800	Handere	Operational	1989
Karkamis Dam	192	Ziyaret	Operational	
Keban Dam	1330	Keban	Operational	1974
Kilickaya Dam	124	Yelkesen	Operational	
Menzelet Dam	248	Sariculur	Operational	
Muratli Dam	115	Muratli village	Operational	2005
Obruk Dam	202		Operational	
Oymapinar Dam	540	Oymapinar-Manavagat	Operational	1984
Ozluce Dam	170		Operational	
Sariar Dam	160	Sariyar	Operational	
Sir Dam	284	Kucksir	Operational	

Anatolia [58, 59]. Turkey has great potential for hydroelectric power, estimated at 433 TW/year; with about 140 being currently used, while it is expected to produce hydroelectric power up to 420 TW annually by 2020 [60, 61].

This huge acceleration of supply in Turkey has led to the beginnings of exploitation, despite the fact that about 60% of its hydropower potential is undeveloped today. Turkey owns more than 500 hydroelectric power plants and operates a total capacity of over 15 GW. Also, there is the potential of 15 GW of hydroelectric power plants under construction. Table 6.3 illustrates the hydroelectric power stations in Turkey [62, 63].

- Wind Energy

The geographical location of Turkey means it is under the influence of various pressure systems. In winter, Anatolia suffers under strong northerly and north-east winds. The western regions suffer under the western and north western wind effects. In the summer, continuous northerly winds blow on the western regions of Turkey. In the eastern and southern regions the northeast winds blow at high speeds [64].

The potential of wind energy in Turkey has been estimated to be about 114 GW in the areas with wind speeds higher than 7.0 m that are located at an altitude of 50 m above the ground. According to studies Turkey can take advantage of 20 GW of wind power immediately. Around 1.8 GW (about 9%) of this potential had been exploited up to the end of 2011, with the most important electrical wind power station set up in 2009 [64]. These stations distribute electricity for the Aegean, the Sea of Marmara, and the Mediterranean regions [65]. Figure 6.4 shows the wind energy source areas suitable for production in Turkey, and the currently producing electrical power areas. Table 6.4 shows the status of wind farms in Turkey.

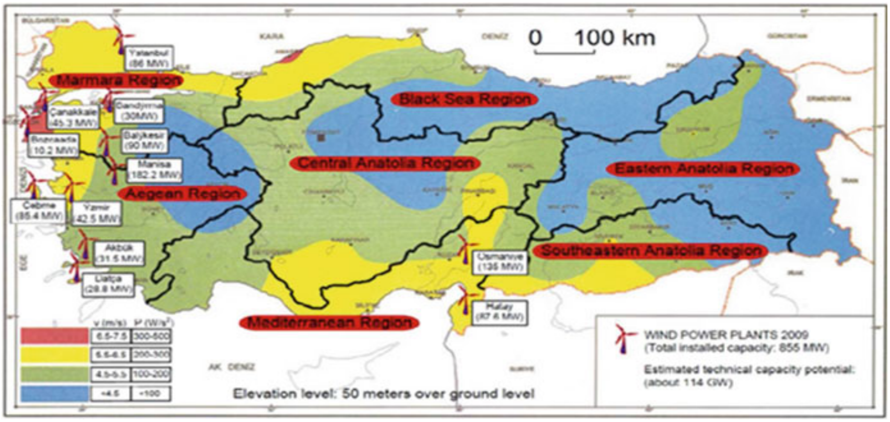

Fig. 6.4 Turkey's wind resource areas and wind power plants in 2009

Table 6.4 Wind farms in Turkey

Wind Farm Station	Capacity	Status
Gokcedag	135	Operational
Bandirma	50	Operational
Bozcaada	10.2	Operational
Soma	140.8	Operational
Karaburun	120	Operational
Geycek	150	Operational
Kangal	128	Operational
Osmanlye	135	Operational
Baglar	100	Operational
Intepe	30.4	Operational
Turguttepe	24	Operational

- Biomass Energy

The estimated natural biomass potential of Turkey is about 372 TWh and includes various sources of agricultural and other waste, such as grain dust, wheat straw, and nuts. It is estimated that about 53% of this waste could be exploited to produce approximately 198 WT of electrical power, while currently only 0.45 TWh are used [66].

The method currently used to convert biomass into electricity is done by the conversion of biomass into hydrogen and carbon dioxide. These gases are burned to run a steam turbine engine at a later time. The synthetic gas production process is complex and needs to purify the product and to intensify the gas, which is a high-cost operation that makes use of this non-commercial technology and not readily available. So, to date, Turkey uses a fraction of these possibilities, and there is no plan of the government to raise the utilization ratio of this renewable resource in the near future [67, 68].

- Solar Energy

Turkey has abundant solar radiation, as it is located in a solar belt between 36° and 42°N latitudes. Most of its regions are suitable for the development of solar energy systems as the annual rate of solar radiation is between 1,120 kWh/m^2 per year in the Black Sea region with 1,971 hours of sun per year. The highest solar radiation recorded in Turkey is higher than 1 460 kWh/year m^2 in Southeast Anatolia with 2993 hours of sun per year [69]. The solar radiation to the rest of Turkey ranges between these two values. Solar power generation now meets about 0.26% of the total demand for electricity of Turkey [70, 71].

The total productive capacity of the solar panels in 2011 was 0.7 MWP. About 4 MW was added to the system in 2012, 50 MW in 2013, and the total output of the power produced by solar energy reached about 1,000 MW in 2014. There are no plans to create greatly beneficial projects before 2014 [75, 76]. Therefore, it is not likely that solar energy will play a key role in Turkey's electricity supply in the near future. Figure 6.5 indicates the solar intensity levels spread over an area of Turkey [77].

Fig. 6.5 Solar radiation levels in Turkey

6.3 Syria

The Syrian Arab Republic has a total area of 180,185 km, bordered on the south and south-east by Iraq, Jordan to the south, Israel to the southwest, and Lebanon to the Mediterranean Sea to the west. The country is divided into 14 provinces, one of which is the capital, Damascus. The state can be divided into four natural geographical regions [78]:

- The coastal area between the mountains and the sea.
- Mountains and high regions extending from north to south along the Mediterranean coast.
- The plains or inland areas located to the east of the highlands, which include the plains of Damascus, Homs, Hama, Aleppo, Hasaka, and Daraa.
- Badia and desert plains south-east of the country, bordered by Jordan and Iraq.

In 2005, the total area of arable land was 91.5 million hectares, or 32% of the country's entire area, while the area of cultivated land was 74.5 million hectares [79].

The climate of the Syrian Arab Republic is Mediterranean (relative to the Mediterranean Sea) with continental influence. Winter is cold and rainy, and the summers are warm and dry. Spring and autumn are relatively short. Large parts of Syria are subject to a high volatility and variability of daily temperatures [80]. The daily temperatures can reach 32 °C in the interior and about 13 °C in coastal areas. The annual precipitation rate ranges from 100 mm to 150 mm in the northwest, 150 mm and 200 mm in the area extending from the south of the country towards the central region, and between 300 mm and 600 mm in the plains. Table 6.5 shows some essential statistics for the composition of this country [81].

Table 6.5 Syrian statistics [82]

Statistics	Quantity	Year	Unit
Basic statistics and population			
Country area	18,518,000	2005	Hectare
Cultivated area	5,742,000	2005	Hectare
As a percentage of the country's area	31	2005	%
Land suitable for growing annual crops	4,873,000	2005	Hectare
Area of permanent crops	869,000	2005	Hectare
Population			
Total population	19,043,000	2005	People
Ratio of rural population to total	49.7	2005	%
Population density	102.8	2005	People/km^2
Proportion of females to total population	28.7	2005	%
Ratio of males to total population	71.3	2005	%
Economy and development			
Gross national product ($ US)	38,080	2007	Million $ US
Gross domestic product per person	1480	2005	$ US/year
Human development index (ID = 1)	0.724	2005	

Table 6.6 The main dams in Syria [84]

Basin	Dam's number	Total storage capacity (million m^3)
Al-Yarmouk	42	245
Coastal Basin	21	602
Al-Aasi	49	1492
Al-Badia Basin	37	69
Euphrates and Alepp.o	4	16,146
Tigris and Khabour	12	1045
Total	165	19,599

In the Syrian Arab Republic, there are 166 dams with a total storage capacity of 7.19 km (Table 6.6). The largest of these dams is Al-Tabka dam on the Euphrates River close to the city of Raqqa. The dam's area is 674 km^2, which represents the dam lakes' area. The most massive dam is Asad dam with a storage capacity of a 41.1 km^2, Qutaina dam has a volume of 200 million m^3, and there are many medium-sized dams, including Al Rastan Dam (228 million m^3). Most of these dams are located near Homs and Hama cities in the west of the country [83].

6.3.1 *Energy Status in Syria*

The electrical power sector in Syria suffered from many problems with regard to production, transmission, distribution, and delivery to consumers. In 1904 electricity was introduced to Damascus City. The electricity development in this country can be divided into four stages: In the first phase (1904–1950), foreign companies controlled the electricity sector. The emergence of national organizations occurred late and concentrated the production and consumption of electricity in the cities: Damascus, Homs, and Aleppo. In the second stage (1951–1965), the government nationalized foreign and national companies, established the General Establishment for Electricity to supervise the electricity sector in the state, introduced electricity to most Syrian cities and some rural areas, and continued production and consumption of electricity concentrated in the three previously mentioned towns. The third stage (1966–1980) is one of the most critical stages of the economic development of electricity in Syria and has witnessed several events that have had a significant impact on the electricity sector, an impact that remains to this day [85, 86]. The most important of these was the establishment of the Ministry of Electricity, the establishment of the unified network, and the construction of the Euphrates Dam and its hydropower station. These events have contributed to changing the geographical distribution of production, which has increased significantly to meet the increasing demand due to population growth and development projects. The geographic distribution of the power plants was changed after the establishment of the Euphrates dam and the unified network to concentrate in the governorates of Raqqa and Hama. Electricity production moved to focus in the two previous provinces, while consumption remained concentrated in the governorates of Damascus, Aleppo, and Homs [87].

The fourth stage (1981–2007) was characterized by a decrease in the quantity of electricity generated from the water plants in the 1980s, which led to a reduction of production and became unable to cope with consumption. The government followed a policy of easing loads. This situation continued until the mid-1990s. A new group of generation plants, some of which are currently the most crucial power plants in Syria, have now entered the service. The most important of these stations, Aleppo Station, is the most significant power plant in Syria, and is the only installed station in Syria so far. The entry of such locations into service has contributed to ameliorating the electricity crisis that ended in the mid-1990s [88].

Syria had 16 power plants in 2007 with a total capacity of 7,157 MW. Water capacity accounted for 21% of them, steam 51.7%, gas 17.5%, and composite cycle 9.8%. The water stations were established on the Euphrates while the thermal stations were located near the consumption centers in the north-south central axis. Aleppo Station is the most abundant power plant in Syria with a nominal capacity of 1,100 MW. Aleppo governorate has the most significant share of the capacity of the generation plants (24.2%), followed by Hama governorate (22.6%) [89].

Fuel oil (diesel) and natural gas are the primary fuels used in the operation of the power plants and are transported to the stations by pipelines, trains, and trucks. Electricity production in Syria has increased in recent years steadily. The production capacity reached 38,642 million kW. In 2007, steam stations were the most productive and contributed a rate of 58.4% of the total production [90]. The output of hydroelectric plants has decreased, and its contribution to production has dropped to 9.1%. It has been dramatically affected by the Turkish projects on the Euphrates River, which is the site of all hydroelectric power plants in Syria. Gas stations accounted for 18.9% of production, while the share of installed cycle stations was 13.6% [91].

Electricity in Syria was one of the most important sources of energy and the cheapest available to all Syrian citizens in 2011. However, power has become a dream for many people after the production plants and the electricity networks of many areas have suffered destruction as a result of war over the last 4 years. Syria relies on two sources of electric power: the generation of electricity by water and by thermal stations deployed in the provinces [92].

The consequences of this destruction include a 60% reduction in gas production, obstruction by fuel has been halted due to the absence of skyscraper and landfill routes, and the lack of periodic maintenance of the generation kits. As a result of these conditions, the capacity generated reduced from about 10,000 MW before the events to about 2,500 MW currently. The production decreased by 75%, where the need for electricity in Syria in 2011 was between 10,000 and 12,000 MW, the generation was 10,000 MW [93]. Electricity is currently produced in the southern and coastal regions of Syria only. Many transfer stations, especially north of Aleppo and Idlib, were damaged and some of them were systematically destroyed almost entirely. The percentage of destruction in some areas of Syria reached 75% of the transmission network and high-tension lines and is completely destroyed in other regions [94].

One of the most important sources of electricity available in Syria is hydropower generation from the dams of Tishrin, Euphrates, and Al-Baath. It is connected to the water supply, making up about 5%. This is used only during the evening rush hour. Turbines are stopped all day, water is reserved, and turbines are thenoperated at peak hours between 5 and 10 pm. The second source of electricity in Syria is the thermal generating plants, which reached 95% of supply. Some of these plants were working on gas and some on fuel and are now stalled because of the lack of transport and land to transport fuel to stations. There are currently 11 thermal generating plants and three hydro thermal power plants in Syria. In Aleppo, the thermal station, Idlib Zizoun, Hama Maharda, Zara and Homs Gendar; Damascus and its villages Deir Ali, Tahrin al-Harari and Nasiriyah, Deir Al-Zor, Al-Taym, and the Swedish in Hasakah and Banias in Tartous. As for the need for the electricity sector in Syria, "Abdulrahman," this industry needs mechanisms, levers, spare parts, and equipment for stations and networks of the normal tension and transfer centers. The Turkish side is currently in contact with the Turkish network and north of Idlib in order to secure a source of electricity [95, 96].

6.3.2 *Renewable Energies in Syria*

Renewable energies in Syria have become one of the priorities of the decision makers. It is expected that the demand for electricity will reach 44,000 MW in 2010 and 70,000 MW per hour in 2020. The Syrian government has begun to develop a plan aimed at exploiting all of the renewable energies in the production of electricity to reduce the demand for fossil fuels in the production of electric power [97].

Recent studies have shown that wind power is available in four regions of Syria that can be invested to build wind farms. These areas are: the west and east of Homs and the eastern foothills of the Sahel Mountains and extend from Idlib, Hama, Ghab, Masayf, and Mashta al-Hilu to the area of the slopes of Mount Sheikh and the maritime sector along the Syrian coast. Studies have shown that the wind speeds in these areas are within the economic investment of wind farms for turbines with a capacity of 2 MWh. Table 6.7 lists the electrical powers produced by wind farms in Syria [98].

Table 6.7 Production of electric power by wind farms [99]

	South Qunitra	Al-Baath city	City of Palmyra	Homes	Safeta
Generators	MW	MW	MW	MW	MW
100 × 200 kW	25,920	33,120	26,260	398,400	10,560
100 × 1 MW	129,600	165,600	130,800	199,200	52,800
100 × 1.2 MW	155,520	198,720	156,960	239,040	63,360
100 × 1.5 MW	194,400	248,400	196,200	298,800	79,200
100 × 2.5 MW	324,000	414,000	327,000	498,000	132,000

The generation of energy from household, petroleum, industrial, and thermal waste has the potential to produce more than 1,000 MW. The waste becomes an energy product rather than an environmental problem in all Syrian cities. According to the study, enough waste is available to produce bio-fuel for the work of heating agricultural and electric power production to cover the needs of many agricultural areas and small cities of more than 2,000 MW/h [100].

The studies pointed out that the cost of investment, i.e., the cost of setting up stations, is higher than that of the plants working on fossil fuels because they do not need any fuel. The energy gets carbon compensation under the Kyoto Protocol and the result is that renewable energy after calculating all costs compared to fossil energy is five times lower than that of fossil fuels based on current oil prices, which are likely to increase in coming years [101].

Recent studies have shown that most waste in electricity consumption is concentrated in the industrial and commercial sectors and public institutions due to the low cost of electricity. The consumption of any industrial product in Syria is equivalent to nine in Europe and America. Therefore, industrialists are encouraged to switch to the production of energy from the sun or wind, where the industrial plant can satisfy its requirements and inject surplus back to the network. Also, the operation of public lighting systems and lighting billboards, parks, traffic systems, and traffic signals through solar energy increases the burden of the network [102].

For solar energy, the precise measurements of solar brightness in Syria were recorded in Abu Shammat, Hasaya, Palmyra, Altnaf, Albuqmal, and Bab Al-Hawa; readings exceeded 7 kW/m^2. These results show that the energy available from wind and solar production in Syria reaches 100 000 MW hours or 14 times the total produced by all the fossil power stations currently in Syria. Syria has the potential to last 100 years without the need for any fossil fuels [103].

6.3.3 Use of Photovoltaics in Syria

Electricity production has fallen by more than half and the impact of infrastructure battles has directly affected this. The Syrian network was classified as one of the "most efficient" systems in the Middle East. The Syrian government has found in the alternative energy projects a solution to provide electricity in its public institutions to manage its affairs in light of the long power outages, which means the absence of complete paralysis, especially in banks and offices of ministries, which are experiencing a substantial demand from the auditors [104, 105].

So, alternative sources of fossil and conventional fuels are the solutions – the wind and the sun, but are such projects successful in the midst of the war? On the individual level and within homes and public institutions where use is limited, such a project can be a solution, but at the level of cities this does not seem plausible. Currently, there are no new domestic or foreign investments, because of the security conditions and daily bombings, only schemes for projects instituted before 2011 are supported [106].

The Syrian government is currently working on a 25 kW PV project that will benefit from solar energy in the production of electricity. The pilot and experimental projects, scientific studies and research in the field of renewable energy applications, and the use of animal and agricultural waste for the production of biogas and solar water pumping systems are being implemented. Solar power generation projects have recently increased in Syria, but these projects have been hit by the hurdle of rising costs and the need for a big budget [107]. The National Energy Research Center (NRC) is working on the installation of a power plant on the roof of the Ministry of Agriculture building with a capacity of 40 000 kW annually, at a cost of 18 million lira. The Ministry of Electricity recently announced its intention to set up the power generation project through the deployment of solar panels on the roofs of 335 schools in Damascus in order to generate 10 kW per school. The project needs 5 years to be implemented [108].

By the beginning of 2015, the official authorities of the system have intensified their efforts to rely on alternative energy in public places and state institutions in various areas under the control of the system. The project was established for the pumping of water from the wells in the Red Valley, the Talila Park, and the Abu Al-Fawares well in the Syrian Desert. In addition, there is the installation of 50 systems for lighting the Al-Qaleela Forest road in Lathakia Governorate producing 140 kW [109].

In the field of solar thermal systems, two projects have been implemented to secure the hot water of Ibn Al-Walid Hospital in Homs at 6,000 L per day, and the Mowasat Hospital in Damascus at 32,000 L per day. A contract was signed for the construction of five PV systems on the roofs of public sector buildings in Damascus with a capacity of 75 kW. Preparations are also underway for the implementation of a pilot project capable of 3 kW on the surface of the school, Jawdat al-Hashemi. Additionally, cooperation with several public bodies is underway to prepare technical studies of some projects such as agriculture, local administration, environment, oil, and others in preparation for implementation within the Center's plan for 2015–2016, Energy No. 3 of 2009 [110]. The first objective of such projects is to spread this culture and to show the need to use renewable energies and the economic feasibility of such schemes. As a result, some public-sector bodies have circulated some of these experiences, especially the projects using water heating systems in hospitals.

The use of alternative energy and reliance on electricity generation is not limited to the government and its institutions, but also to citizens in areas of control and opposition control areas. After 5 years of a suffocating war, the Syrians created new roads to generate electricity by solar panels after the electricity was completely cut off because of military operations [111].

The Syrian citizen is able to provide full lighting for his home for about 6 h a day, but the cost is "very high," under difficult living conditions experienced by the Syrian citizen, and the possibility of the panels breaking is high, especially in areas under constant bombardment. The current circumstances have prompted many families in Syria to rely on this method of energy, which costs an average of approximately one million Syrian Pounds ($2400). It has led to a rebound in the trade of solar panels, and as a practical alternative to generators that operate on high-priced fuel derivatives, but this method is useful compared to the age of default, which extends for more than 15 years if used correctly [112].

Even if the war is over and the sound of the guns dwindles, the alternative energy option remains a must. Many of the recommendations and studies indicate that energy required for the reconstruction of Syria will not be satisfied by the oil and fuel extracted from its fields. Construction companies need new energy sources of approximately $250 billion to rebuild Syria, according to UN estimates. Perhaps the wind and the sun are the best options [113, 114].

6.4 Kuwait

The State of Kuwait is located in the northeast corner of the Arabian Peninsula, with a total area of 17,820 km^2. It has a combined land border with the Republic of Iraq and Saudi Arabia of about 490 km. Its coastline on the Arabian Gulf is approximately 500 km [115]. Kuwait consists of deserts of soft sand, bulk, and flat areas with some hills (Jal Al-Zor Hills series), most of which are dry and desolate [116].

Kuwait is located in subtropical regions characterized by their relative warmth in winter and high temperatures in summer. Furthermore, in the summer there is about 14 h of sunrise. Drought is a distinctive feature of Kuwait, where rain is rare, slow, and fluctuates in quantity [117]. When it falls after several years of drought, it is abundant, concentrated for a few hours, and often followed by floods that cause severe damage to soil and vegetation. The desert environment covers at least 90% of the country's total area [118].

Kuwait's climate is characterized by two main seasons, a long hot, dry summer where the highest temperatures are usually recorded and a short winter with limited rain and relatively warm temperatures; in summer the temperature rises sharply, the maximum being during July and August [119]. The main reason for this climatic effect is the intensity of solar radiation. It is well known that clouds isolate the earth during the day, and inhibit the worst of the heat of the sun, and then during the night the same clouds have the task of storing the temperature of the earth and preventing it from dissipating into space. Without clouds the heat intensifies under the weight of the high desert sun, then it loses temperature quickly a second time at sunset [120, 121].

January is the coldest month of the year locally, with a monthly average temperature of about 13 °C, and a maximum temperature of about 18 °C, while the minimum temperature is about 8 °C. The weather is mild in the winter even in the coldest months of the year, but at night it is very cold as the temperature is reduced significantly [121].

Northwest winds predominate in Kuwait during the summer months, with a local rate of about 60%; these winds are high speed, high temperature, dry winds. They are due to the high atmospheric pressure behind the Mediterranean and Southern Europe in the north, and the low-pressure centers along the tropical front in the south. This front lies south of Kuwait by 600–800 km [122].

Another feature of the desert is the sandstorms (about 154 days/year). The sand and dust that blow through the desert plains make life unsuitable for plants and animals. When sandstorms blow, the desert creatures avoid these winds by hiding and keeping away from them as much as possible. Dust phenomena persist over the summer months, and there are an average of about 26 dust storms a year, a rate that is more than twice the average in neighboring countries [123, 124].

Fresh, brackish groundwater is the only natural source of water in Kuwait. The availability of this water was one of the most important factors to attract people to stay in Kuwait in the past and the most important of these wells are Shami, Kifan, Hawli, Nqqah, Dasamah, Surat, and Salmiya. In addition there are also wells located on the southern coast and also in the Jahra. In general their depth is a few feet [125, 126].

6.4.1 Energy Status in Kuwait

On 23 December 1934, the Prince of Kuwait was awarded by the Kuwait Oil Company Limited, which was established as a private joint venture between BP and the Gulf Oil Company (Gulf Oil, currently Chevron), the concession of exploration for oil [127]. After World War II, Kuwait was transformed from a poor desert state into a modern rich state. The first oil field in Kuwait was discovered in the Burgan area, and drilling operations were carried out in 1937 and early 1938. On 22 February 1938, oil was discovered in Burgan. On 30 June 1946 Kuwait began exporting the first shipment of Kuwaiti crude oil. Thus, Kuwait joined the ranks of the world's major oil producers [128].

In the three decades following that date, there were significant developments. KOC commenced refining operations at Mina Al Ahmadi refinery in 1949 and established Kuwait Oil Tankers Company in 1957 [129]. Kuwait National Petroleum Company (KNPC) was established in 1960 as a public and private-owned company and commenced operations at Shuaiba Refinery in 1968. The petroleum chemical company that was established in 1963 was also a project between the government and the private sector, and began in the following year its operations of manufacturing oil derivatives. Kuwait nationalized the oil industry on 6 December 1975, after signing an agreement between the State of Kuwait and British Petroleum, and the Gulf Oil Company to regain full control over the oil resources of the State of Kuwait. It is eighth in the list of the countries of the world's top crude oil exporters, with a volume of 3,188,000 barrels per day [130].

Despite its oil wealth, Kuwait entered the era of gas in 2006, when more than 34 trillion cubic feet of pure gas were discovered in four fields in the north of the country by the Kuwait Oil Company. After 8 years of digging the first wells, Kuwait is now ready to produce non-associated gas for oil. Kuwait will provide more than 300,000 barrels per day of condensate gas, along with 3,000 tons of ethane and 3,000

Table 6.8 Kuwait consumption of fossil energy for the period from 2009 to 2012

	2009	2010	2011	2012
Consumption of petroleum products	6,476,564	6,418,503	5,692,265	5,637,069.9
Natural gas consumption	3,796,982	5,305,223	6,102,804	6,679,220.9
Total primary energy consumption	10,273,546	11,723,726	11,795,069	12,316,290.8
Per capita primary energy consumption (kg/person)	2940	3270	3190	3220

tons of propane and butane. It will also produce 750 tonnes per day of sulfur that may be stored underground or exported. Table 6.8 shows the consumption of fossil fuels by Kuwait [131, 132].

6.4.2 *Electricity in Kuwait*

The discovery of oil in Kuwait (which is still the main source of national revenue) was the beginning of the civilizational renaissance of the country, which included all aspects of social, urban, educational, and economic life. Electricity played an essential role in the renaissance of the country by meeting its needs with a significant development with time.

In 1934, the first power plant in Kuwait was established with the establishment of the first small power station to generate electricity from the local electricity company [133]. The production started with the installation of two generators with a capacity of 30 kW, and the current distribution was 200 volts. At the end of the first year, the number of subscribers was not very high: there were only 60 participants. However, the number of subscribers in 1940 increased to about 700 and the installed capacity increased to 340 kW [134].

As a result of the effects of the Second World War, there has been a period of stagnation in the development of this sector. By the end of the war, the company decided to cancel the DC system gradually and introducing three-phase AC system with 380/220 volts and frequancy of 50 Hz. The company set up the generating station in Al-Mirqab, which included two generators of 200 kW that began operation in early 1949, and a third generator with a capacity of 200 kW was added as well as a permanent system of fire extinguishing was discontinued in 1950. In order to cope with the increasing demand for electricity, the company acquired a 500-kW generator from the Kuwait Oil Company early in 1951; the combined generating capacity was 1,100 kW (1.1 MW) [135].

As a result of the rapid revival of the country in various avenues of life, the demand for electricity has increased to a large extent, making existing plants unable to meet this need. The government found that the time had come for an intervention. General Electricity was responsible for the provision and distribution of sufficient electrical power [136].

Table 6.9 The electricity consumption data in Kuwait for the period 2009 to 2012

	2009	2010	2011	2012
Combined electrical power	12,579	13,382	14,702	15,349
Steam power stations	9630	9745	9745	9745
Gas power stations	2948	3637	4597	4597
Dual cycle stations	–	–	360	1000

Table 6.10 Electricity consumption in different sectors in Kuwait (Giga watt hours) for the period 2009 to 2012

Final energy consumption sectors	2009	2010	2011	2012
Industry sector	5592	6022	6045	6448
Residential buildings sector	22,368	24,089	24,180	25,794
Other sectors	18,640	20,074	20,150	21,495
Total final power consumption	466,400	50,185	50,375	53,777

The peak load was about 32% in the 1950s, 26% in the 1960s, 15% in the 1970s, 8% in the 1980s and 11% in the 1990s. Global standards, still considered high, were in the range of 5–8%, while most industrialized countries do not exceed an electrical load of more than 2–3% per year. In some countries, however, it is lower, and of course, the growth in populations and thus electric consumption is a direct reflection of these conditions. Climate and rapid economic and urban development in the country in both the public and private sectors, and the rise in the individual rate of electricity consumption reflects and indicates the existence of some aspects of consumption extravagance encouraged by the low cost of electricity. Table 6.9 shows the development of power and electric power produced in Kuwait for the period from 2009 to 2012 [137, 138] (Table 6.10).

The Electricity Authority took responsibility in 1952 when it built the first electric power plant in the Shuwaikh area near the coast in order to use the seawater in the cooling operations. Initially, this station consisted of three 750-kW small steam units, equipped with steam. The first desalination plant was stopped after station A was installed in 1954–5, with a capacity of 7.5 × 4 MW [139]. The construction of station B in 1958 had a capacity of 4 × 10 MW (suspended in 1978) and station C 61 in 1962 with a capacity of 3 × 30 MW. In 1977, five gas-generating units of 40.8 MW were added. The combined capacity of the plant was 324 MW, and the installed capacity in 1989 was reduced to 208.2 MW. Four steam units (installed capacity 75 MW) and a gas unit (installed capacity 40.8 MW) were put out of service due to their low efficiency or lack of economic feasibility for repair (33 million kW hours). In 1990, the plant was completely shut down as a result of the destruction caused by the Gulf war [140].

The first source of electricity and fresh water consumed in Kuwait is from generating plants and distillation. These stations include unique and sophisticated equipment that requires substantial financial investments. In these stations, vast amounts of fuel are burned, and they are converted to produce large quantities of compressed steam at very high temperatures to operate steam turbines. The power facility uses steam thermal turbines mainly to generate the electric power needed to meet the electrical demand. Furthermore, some of the gas turbines, which constitute about 28.7% of the total installed capacity, are used in the generation plants and are used in emergency situations and when the maximum electrical load usually occurs [141, 142].

The electric power generation in Kuwait during the last five decades has developed in both quantity and quality. After the implementation of the first steam station in 1952 with a total capacity of 2.25 MW (three units capacity of 0.75 MW), in 1984 the capacity jumped to about 2,400 MW (eight units of the capacity of 300 MW). Also, to the South the Zor station and the Sabia station were established, all of which are still in service [143]. The construction of larger plants with larger units and sizes was to meet the increasing high rates of demand in the country due to the economic and social situation and the sharp increase in the population resulting from the introduction of about 4 million new arrivals [144].The fossil fuels available in Kuwait (natural gas, heavy fuel oil, crude oil, and gas oil) are used to operate the power plants according to the design of the boilers in the stations and are currently priority is given to natural gas and the quantities available. At the time the old gas stations were burned in addition to the gas oil in case of emergency only, but modern stations were designed to burn all four types of fuel [145].

Statistics show that the installed power of the stations in 2009 amounted to 12,579 megawatts, noting that the maximum electric load reached 9,960 MW in 2009. The Kuwaiti government has increased the sizes of production units from 7.5 MW to 10 MW to 300 MW. In this way, Kuwait took advantage from the economies of scale characterized by large units that led to reduced operating and maintenance costs and higher efficiency and productivity, which had a positive impact on the cost of production [146].

6.4.3 Renewable Energies in Kuwait

Due to its geographical location and climactic conditions, Kuwait has the opportunity to use much renewable energy for electricity generation. Solar energy is available most of the year in addition to wind power due to the long coast bordering Kuwait from the east and eight islands in the sea. Kuwait's coastal location also enables it to use the energy of the waves [147].

The most important obstacles to the spread of the use of renewable energies in Kuwait, despite the high financial potential to invest in this area, is the availability of cheap fossil fuels so that the establishment of renewable energy plants will be economically viable when compared to fossil fuel stations [148].

However, several Kuwaiti parties have made attempts to introduce renewable energy into electricity production. Electricity produced from the sun and wind have become a reality after the Shqaya renewable energy complex was connected to the national electricity grid and the country was supplied with about 23 million kWh in 6 months [149].

The Kuwait Institute for Scientific Research (KISR) has been able to assist the Petroleum Corporation and the Ministry of Electricity of Kuwait to carry out numerous studies to benefit from renewable energy and make it a competitor to oil (Kuwait's primary source of income). Studies focused on the transformation of renewable energies into an opportunity for investment and an economic project with a material and environmental return. The Shqaya project in the west of the country was the result of these intense efforts and will open the way for the private sector to invest in the coming stages and encourage innovation and invention [150]. This complex includes two plants for the production of renewable energy: first the station at Al-Shqaya solar PV and the other at Shqaya wind power station. The total of exported clean electric power is 23 million kW-hours, sufficient to provide full electricity to 130 houses a month, contributing to the provision of 40 thousand barrels of oil worth in the world market at 600 thousand dinars [151].

The developments in the production of renewable energy equipment have made the cost of producing electricity from renewable sources competitive when built in traditional ways. The total cost of providing energy from the Shqaya complex in the past 6 months reached 400,000 dinars, with a financial abundance of 160 thousand dinars of traditional power [98].

Kuwait has a population of about 4.4 million, according to the latest figures of the Central Administration of Statistics, and consumes nearly 350 thousand barrels per day of oil for electricity generation and desalination, worth approximately US$15.7 million (based on the price of US$45 per barrel of oil). The Ministry of Oil forecast an increase in the demand for energy to one million barrels of oil per day by 2035 with the population of Kuwait to expanding to 5 million and a half million people [152].

Kuwait today occupies an advanced position among the GCC countries in the production of electric power from the wind generated by the project (Shqaya), engaging in visits from sister countries to discuss the sharing of experience [153]. The role of the oil sector in the innovations and experiments and the use of alternative energy, such as KOC, implemented the first renewable energy projects in Kuwait. The project (Sidra 500) in the region (Um Qadir) west of the country, which already began work in October 2015 and generates 10 MW Of electricity from solar energy, supplies half of the public electricity network. The other half is used in the industrial lifts of wells within the oil field of Um Qadir [154].

One of the most significant projects awaiting Kuwait, according to the Kuwait Petroleum Corporation (KPC), is the Dabdabah solar power project with a capacity of 1,000 megawatts, an initiative announced by the Corporation to benefit from renewable sources of energy by establishing a solar power station capable of securing 15% by 2020 [155].

6.4.4 Solar Photovoltaic Applications in Kuwait

The consultant of the Renewable Energy Organization of the United Nations Global Charter expert Dr. Eric Rowland said that Kuwait could rely 100% on solar energy in generating electricity if it allocated 2.7% of its area for this purpose. The country has solar power that can cover all the stations in the world at the moment [156].

The first applications of solar technology in the Kuwaiti oil sector to benefit from the sources and applications of renewable energy technologies was to meet part of the needs of the Kuwaiti oil sector of energy. The Kuwait Institute for Scientific Research (KISR) conducted a research study to assess the technical and economic feasibility of applications of solar technology in the Kuwaiti oil sector. The study included a comprehensive review of the various techniques of solar energy utilization and the role of the international oil companies in exploiting this source of energy and the current economic feasibility of solar energy exploitation [157]. A preliminary survey of energy consumption was conducted in many of the buildings and industrial facilities of the Corporation and its subsidiaries to facilitate decisions regarding the selection of solar energy projects [158].

The joint cooperation between the Kuwait Oil Company (KOC) and the Kuwait Institute for Scientific Research (KISR) and the technical support of the German universities of Fahrenheit Hover and Kassel have demonstrated the application of various solar technologies in the different facilities of the Kuwait Oil Company. These services were mainly in the field of protecting the local environment and reducing harmful emissions, including the emission of carbon dioxide and other greenhouse gases that cause global warming and climate change [159].

A second phase of the project has been initiated to include the implementation of many solar energy applications in the oil sector as pilot projects to evaluate their actual technical and economic performance. These applications will enable training and development of human resources in the field of solar energy applications in the Kuwaiti environment [160]. The second stage of the project involves two primary claims. The first aims to use solar cells to generate electricity at a gas station by exploiting the available space in this plant to install the solar panels. Thereafter they will be connect to the main electricity grid to export the surplus electrical energy resulting in reducing the required electrical load from generation plants of the Ministry of Electricity and Water. As a result, the emission of harmful gases will be reduced [161].

The second application aims to use solar thermal energy by solar heaters to supply the oil collection centers with the thermal energy needed for the initial processing of crude oil. The role of solar heaters will be to take advantage of clean solar thermal power to raise the temperature of the oil to the equivalent of 120 °C instead using gas as currently occurs [162].

The Kuwaiti government is also working to raise awareness of the use of solar cells in homes to take into account when building a new house that operates on solar energy, having some considerations for the home or the area where it is built. These concerns include [163]:

- The best places to put the large windows are the north and the eastern and western sides depending on the location of the building. For example, the Diabetes Treatment Center in East Governate where small openings were placed on the southern side and designed in a way that makes the structure harmonious.
- The roof of the house should be designed with two levels, the first as roof space and the second for the solar panels.
- Water tanks used in many homes are placed on the northern side; they should not affect the fall of the sun.
- The use of C L F lighting bulbs, an economic type that provides 75% of the electricity consumption to get the most benefit from the commercial project.

The Government of Kuwait has set the goal of contributing to the renewable energy generation in Kuwait between 2015 and 2003 up to 15% of the total electricity generated. Regrettably, the Kuwaiti government has not yet enacted laws or legislation relating to renewable energy and energy efficiency. Kuwait has two centers for renewable energy research. The first is the Kuwait Institute for Scientific Research (KISR), which signed in March 2015 a contract for Phase 5 of the Renewable Energy Initiative. This arrangement is for the design and construction of the first 10 MW wind power plant [164]. The second center is the Kuwait Foundation for the Advancement of Science (KFAS). The two centers work separately to encourage scientifically applied research to improve and develop the national economy. Kuwait is contributing to the project of electrical interconnection of the Arab Gulf States, a unique project that will achieve integration and unity of electricity of these countries to contribute to the development of their societies and reduce the pressure on their economies [165].

6.5 Saudi Arabia

The Kingdom of Saudi Arabia is located on the Arabian Peninsula, in the extreme south-west of Asia. Its territory is between the latitudes of 16° and 32° north and the longitudes of 30° and 55° east. The Tropic of Cancer orbit lies across its center. The Kingdom covers about 2 million km^2, covering about 70% of the sub-area of the Arabian Peninsula, which is approximately 2.8 million km^2 [166]. The Kingdom is divided into 13 regions, each divided into provinces. The Kingdom of Saudi Arabia is bordered by seven Arab countries with a total land length of 4,531 km. The Kingdom of Jordan, the Republic of Iraq, the State of Kuwait, the State of Qatar, the United Arab Emirates, the Sultanate of Oman, and the Republic of Yemen are adjacent. The Kingdom also has coastlines extending over the Arabian Gulf and the Red Sea along a length of 2,330 km [167].

The total population of the Kingdom was 27,136,977 according to the general population census for 2010. The number of Saudi citizens is 18,707,576, representing 68.8% of the entire population of the Kingdom. The non-Saudi population is 31.1% of the total population of the Kingdom. In the past five decades, the birth rate has been estimated at 40 per thousand and is considered to be high. The mortality rate is also high, exceeding 30 per thousand, but it has been declining due to increased healthcare, improved nutrition and hygiene, epidemic control, and improved living standards [168].

Immigration in the Kingdom was a prominent phenomenon, especially in the middle of the last century, although it has varied from time to time. There is a link between migration and comprehensive development plans, which were at their height in the 1970s and 1980s. The annual population growth rate was 4.9% and 5.7% in the period 1962–1974 and 1974–1993, respectively [169].

The Kingdom's surface consists of the coastal plains, such as the coastal plain of the Red Sea and the coastal plain of the Arabian Gulf. The Kingdom has a mountain chain extending along the coast of the Gulf of Aqaba and the Red Sea, from Jordan's border north to the Kingdom's borders with the Republic of Yemen to the south. In addition there are several mountain formations, most notably Sarawat, Hijaz, and Madin Mountains. In the Kingdom there are several plateaus located to the east of the western highlands, covering large areas of their lands, and from these the hills Najran and Asir, Hejaz, Hasmi, and the central and eastern plateaus [170].

The sand communities cover a large area of the Kingdom with an area of about 635,000 km^2, representing about 33% of the Kingdom's area. The sand communities are spread across many regions of Saudi Arabia, the most important of which is the desert of the Empty Quarter. The dunes have been formed as a result of numerous factors, such as the presence of sources of sediment, watercourses, high winds, and various terrains leading to the barges. Wind plays a significant role in the formation of sand communities, as it conducts the sculpting, transport, and sedimentation of the earthworks and plankton, and plays an essential role in the distribution and formation of sand formations [171, 172].

Hundreds of seasonal waterways, most of which are formed during the rainy season, spread over the Kingdom's surface. They are distributed throughout the Kingdom, but are lower in the southern part of the eastern region and are absent in the Empty Quarter. The principal waterways are called valleys and streams, and the naming of the tributaries varies from one area to another according to their composition, size, characteristics, and location. Many of the water resources of the lowlands are spread on the surface of the Kingdom [173]. The reason for their formation is that sea water is receding from some lands near the coasts. These fisheries are made up in and near coastal areas as well as they are formed in the remains of ancient lakes. As for their soil, it is of the porous type; and suitable for agriculture. Sometimes, the same soil is not porous and represent the saline, saplings, and salty soil [174].

Heavy rains sometimes lead to sudden flash floods for short periods. A portion of the surface water is carried out through the sedimentary layers of the valleys, and the groundwater is replenished while some of the water generated by the sea is lost. The most significant amount of water flow occurs in the western region, accounting for 60% of the total flow of water, although it covers only 10% of the country's entire area. The remaining 40% of the overall water flow is located in the southernmost part of the West Coast (Tihama), covering only 2% of the total area of the Kingdom.

Renewable surface water resources are estimated at 3% per year. Groundwater is stored in six sedimentary layers carrying old integrated water located in the eastern and central parts of the country. This groundwater is confined to cracks extending along the eastern side at a distance of 1,200 km to the north [175].

Saudi Arabia is the most significant producer of water diverted from seawater. In 2004, there were 30 desalination plants, 24 of which were on the West Coast and six on the East Coast. Recycled water is used for household purposes. The quantities produced cover about 48% of household uses. Indeed, desalinated water is sometimes exported to cities over long distances. The total length of pipelines used to transport desalinated water is about 156.4 km. The capacity of these water reservoirs is 38.9 million m^3 [176].

Most of the Kingdom's area is located in the dry tropical desert range. It is located in the tropical high-pressure zone in winter making it susceptible to dry continental winds. The Kingdom's climate is characterized by drought throughout the year and high summer temperatures [177]. The Kingdom lies in the middle of a continental mass. The sea does not encroach in most parts, but the Red Sea is located in the west and the Arabian Gulf in the east, both of which are narrow, so their effect is limited to increasing humidity in the coastal areas and they have no impact on increasing rainfall. The presence of mountains in the west prevents the influence of the sea further inland. In addition, the dunes in the east prevent marine influences in the south, and the presence of Hadramaut Heights and the dunes of the large empty quarter buffer the effects of the Indian Ocean further inland [178]. The Kingdom's climate is influenced by the masses air pressure coming from Asia, Africa, and Europe. In addition, the Kingdom is dominated by Siberian influences in the winter, Indian and African influences sometimes in the summer, and a lack of marine influences from the Mediterranean and Red Seas and Indian Ocean [179].

The location of the Kingdom within the orbital circumference provides for a climate with high temperatures, in addition to an intense brightness of up to 3,500 h/year in some areas. The temperature is high in summer, but more so in the south than the north, and more so in the center than on the coast. The highest temperatures are in July, and the lowest in January [180]. Most areas of the Kingdom are warm in winter, and the temperature in winter is lower in the north because of the distance from the Tropic of Cancer's orbit. Coastal regions are characterized by high relative humidity, while inland regions have low humidity. Rain falls in small quantities, which justifies the limited vegetation cover in the Kingdom [181].

6.5.1 Energy in Saudi Arabia

Saudi Arabia's fixed crude oil reserves stood at 266.58 billion barrels at the end of 2014, up from 0.79 billion riyals in the previous year. According to SAMA, the Kingdom's fixed reserves rose 2.1% to reach 299.74 trillion barrels at the end of 2014, compared to 293.68 trillion standard cubic feet by the end of 2013. Saudi Arabia's crude oil production in 2014 increased by 8.0% to reach 3545.1 million barrels in 2013, thus averaging the Kingdom's daily production for 2014 at about 9.71 million barrels [182]. According to official data, the kingdom's output of refined products increased by 19.6% to reach 803.8 million barrels compared to 672.2 million barrels in 2013. The Kingdom's daily production of refined products is about 2.20 million barrels per day. At the same time, total domestic consumption of refined products, crude oil, and natural gas rose by 6.7% in 2014 to reach 1516.8 million barrels compared to 1422.0 million barrels in 2013 [183].

Saudi Arabia ranks sixth in world-proven natural gas reserves and ranks third in the Middle East. In 2014, Saudi Arabia produced 4.102 billion cubic meters of natural gas and in the same year was the world's fifth largest gas consumer [184]. In 2015, it was the seventh largest gas producer in the world. In addition, the Kingdom is among the top five countries in the world in the reserves of rock gas, estimated at having 645 trillion cubic feet, and 285 trillion cubic feet of natural gas. The Kingdom consumes most of its production (not exported or imported) from natural gas in the petrochemicals and power generation sector, with natural gas accounting for 40.7% of the country's primary energy needs [185]. This is in line with the vision of the Saudi government, the trend to increase the production of electric power to meet the steady population growth on the one hand and to meet the requirements of the future in expanding the Kingdom's non-oil exports. The petrochemical sector, for instance, has been considered a significant resource for generating electricity and securing development priorities in Saudi Arabia. The reliance on natural gas in electricity generation will contribute to reducing carbon dioxide emissions and underline Saudi Arabia's commitment to the outcomes of international agreements to address climate change. The replacement of oil will also help to use natural gas to preserve the economic value of oil from waste [186].

Saudi Arabia is planning to become a producer of shale gas by 2020. Saudi Aramco plans to invest about US$7 billion in developing rock resources in the Kingdom using modern technologies such as dry drilling to overcome the problem of water scarcity in the process of extracting shale gas [187].

Investment in the development of natural gas inside and outside the Kingdom (such as the partnership project with Russia in the Arctic LNG) is a strategic objective and essential future step in what is known as the global shift in energy towards low-carbon economies to focus on global investment for decades to come. The investment in gas will contribute to the realization of Saudi Arabia's vision to diversify sources of income and reduce dependence on oil to build the Saudi economy and contribute to securing a sustainable future for reliable and clean energy resources such as natural gas [188].

6.5.2 Electricity in Saudi Arabia

Like any other country, the original implementation of electricity was in densely populated cities that were beginning to see active trade and stable communities. However, what distinguishes the experience of the Kingdom in this regard is the individual efforts and cooperative societies that initiated the production of electricity [189]. These efforts were concentrated in the holy cities of Makkah and Madinah because they bring together the two Holy Mosques and the Holy Places. The first city in the Kingdom that experienced electricity was Medina, through lighting the Prophet's Mosque in 1909. In 1919, the Holy Mosque of Makkah was illuminated. The most critical development or what can be called the birth of real electricity in the Kingdom was its introduction in 1933 when oil exploration began in the Kingdom, and mobile generators were used in the drilling and lighting; this use increased following the discovery of the flow of oil in 1938 [190]. The Saudi government then imported electrical generators to support the illumination of the two holy mosques and some government departments. and encouraged individuals and cooperative societies in small towns and villages to form local electricity companies to meet the needs of the population for electric power. It even provided financial support, loans, subsidies, and other facilities including land and fuel for plants [191].

The Saudi government has realized the need for electricity regulations after the electricity sector expanded significantly due to the growing number of companies. The Ministry of Commerce and Industry was established in 1961 in the Department of Electricity Affairs. Its duties are limited to granting licenses and setting up controls to promote the electricity sector. The Electricity Services Department contributed to the generalization of electricity through the development of necessary plans and studies [192]. The introduction of the General Establishment for Electricity has had a significant impact on the development of the electricity sector in the various areas covered by the different development plans. It has implemented many central projects in the fields of generation, transmission, and distribution. It has activities in the fields of loaning of generators and operation and maintenance of electrical projects. During this phase, about 100 companies and a cooperative association were formed to generate electricity, which was relatively developed. However, with the largely urban, industrial, and agricultural expansion, there was a need to meet the increasing demand for power [193]. The first long-term plan expected that the electric loads at the end of the plan will reach 32,000 MW and that the annual per capita consumption of electricity will reach about 8,000 kW compared to 530 kW at the introduction of power in the Kingdom. The results of extensive studies of the development of loads showed that the average annual growth rate of loads reached 4.5%, which would increase the total load of the Kingdom by more than 59,000 MW by the end of the plan in 2022. Accordingly, the entire generation capacity required to meet loads at the end of the program was estimated at 69,000 MW [194].

Saudi Arabia is experiencing an "excessive rise" in annual energy consumption in domestic markets, reaching 240.288 gigawatts per year in 2012, with a per capita consumption of 8.23 MW per hour, or twice the average, the report said. As for the Kingdom's consumption of primary energy, the report indicates that the country needs more than four million barrels of oil equivalent per day to meet domestic demand. This value is one of the highest levels of consumption in the world, even though the Kingdom is the world's leading oil exporter daily with about ten million barrels [195]. According to the report, the approximately 20 million air conditioners in the country “consume more than half of the electricity produced in the Kingdom” and government agencies are seeking “to apply global standards to all air conditioners produced locally or imported to increase efficiency and reduce of its electricity consumption.” Air conditioners consume 51% of electricity production in the kingdom, and the rate rises even more during peak hours, the report stated. Since the beginning of 2014, the Ministry of Trade and Industry has been carrying out a mandatory market energy efficiency campaign through tight control around air conditioning devices [196].

It is noteworthy that an economic report prepared by the group “Citigroup” indicated less than 2 years ago the possibility of Saudi Arabia becoming an importer of oil after two decades, due to high domestic consumption, especially in the field of electricity for air conditioners. Experts in Saudi Arabia have rejected the report, stressing that it is based on inaccurate data [197].

The electricity crisis in Saudi Arabia has entered a new stage after continuous interruptions, and the frequent interruption of electricity in many Saudi regions has placed an additional burden on citizens and residents, especially with the urgent need to use air conditioners and refrigerators under high temperatures [198].

That electricity production rose in 2016 by 8.8%. Electricity consumption in most countries of the world is growing at an average of 2–4% per year at the most, while the growth of electricity consumption in the Kingdom is increasing dramatically. This has raised alarm bells, because it exceeds population growth rates, consumers, and output [199]. If consumption growth continues, the sector will need massive investments in the future to cope with the growth in consumption. Moreover, increasing production will require the need to direct increasing quantities of Saudi Arabia’s oil production toward output. These high rates of growth in electricity production have necessitated the structural review of various consumption patterns in the Kingdom. There is currently a search for ways to reduce consumption growth in this way, study the different waste aspects of it, and look for ways to stop this waste, as well as to examine the suitability of the current pricing of electricity [200].

Low electricity pricing in Saudi Arabia has caused growth in excessive consumption since the state does not receive the real cost from the consumer. The growth of electricity production in such a significant way will increase the opportunity cost of oil destined for generating electricity and deprive the state’s general budget of the proceeds from the sale of this oil externally [201]. Saudi Arabia announced that it would raise the price of fuel and other petroleum products, water, electricity, and others by up to 67% on the same day that the 2016 budget was announced with a projected deficit of $87 billion. Fuel prices in the Kingdom are one of the lowest in the world. The move follows the footsteps of the other Gulf States such as the United Arab Emirates, which in 2017 became the first country in the region to lift subsidies on fuel [202].

6.5.3 Renewable energies in Saudi Arabia

The large area that makes up Saudi Arabia and its geological and environmental diversity make for varied and high quantities of renewable energies. In addition, there is the intense solar energy available to the Kingdom for long periods, as the solar radiation is the highest in the world, Saudi Arabia being located within the solar belt. There is also wind power as the topographical diversity of Saudi Arabia makes wind movement feasible to generate electricity economically. In addition, the coastal area stretches for thousands of kilometers, making the use of wind turbines in these areas is excellent. The utilization of tides in addition to wave movement in power generation has reached a scientifically advanced stage and can also be of benefit to the Kingdom [203].

In a move to increase electricity generation using renewable energy, the Saudi government announced the first wind-power project in a new indication that the Kingdom is moving towards expanding renewable energy utilization and increasing the private sector's contribution to renewable energy. The name of this project is Dumat al-Jandal in the Al-Jouf region and is planned to produce 400 MW of electricity by wind energy. The Kingdom plans to launch 700 MW projects in the first phase of the 2017 National Renewable Energy Program, a step towards achieving ambitious targets for the addition of 9,500 MW of renewable electricity by 2023 [204].

Although the kingdom has a strong investment in solar and wind power, it does not yet have a competitive renewable energy sector. So the goal is to settle a large proportion of the renewable energy value chain in our economy, including R&D, manufacturing, and other steps. Starting with inputs such as silica and petrochemicals, a legal and regulatory framework will be established that allows the private sector to own and invest in the renewable energy sector and provide the necessary funding through public-private partnerships in industry to further advance the industry and build the skills base that is needed [205, 206].

6.5.4 Solar Photovoltaic in Saudi Arabia

While the government of the Kingdom is involved in activating the oil sector and solving problems that have surfaced in the past few years, because of falling prices, Saudi Arabia has also been interested in the renewable energy sector in all its forms, in discovering its secrets and pumping more investments into it. This is because oil is a depleting substance, no matter how long it takes. An alternative must be found as soon as possible [207]. Although oil prices have risen in the global energy market, surpassing the $60 in 2017, which gives a good indicator of the Kingdom's economy, this has not deterred it from continuing its trend in activating renewable energy projects and encouraging businesses and individuals to participate in renewable energy projects [208].

The use of energy substitutes is essential; the first is to make the period of use of oil energy as long as possible and second is the development of another source of energy concurrent with the oil source. The increase in electricity consumption in Saudi Arabia is at an annual growth rate of 5% and over the next 25 years the country is expected to invest $117 billion in the energy sector. The generation capacity in the Kingdom is currently 25,000 MW and is expected to reach 66,400 MW in 2023 [209].

In the last few years, the Kingdom has witnessed unlimited official movement toward the funding of alternative energy projects, according to well thought out plans that ultimately will contribute to securing 50% of the Kingdom's energy needs from alternative sources, including the production of 1,950 MW of solar energy alone. That is one of the primary objectives of the vision and planning of the Kingdom up to 2030, which is focused on reducing dependence on oil as a major source of national income and dealing with the beginning of the post-oil era, especially after the fluctuations of oil prices in the past 4 years, and its decline to more than 55% of the price in 2008. There is turmoil and confusion in the budgets of oil-producing countries, especially the Gulf Arab states [210].

The Kingdom seeks through the King Abdullah City of Atomic and Renewable Energy to activate and develop a sustainable economic system for alternative energy through the addition of atomic and renewable energy sources to oil energy sources, which are consumed in the production of electricity and water desalination. The city has earlier announced its proposals on sustainable energy sources and their target capacity, which will be gradually phased out and reach 50% of the Kingdom's energy needs by the year 2030. Today, the city leads the Kingdom in activating alternative energy projects, and announced a package of projects in the framework of seeing heightened renewable energy sector. These projects include the national plan to measure renewable energy sources at the level of the Kingdom (solar energy, wind energy, and energy waste conversion, energy, and subsoil) [211]. In addition, the projects include collecting totalitarian ground readings from different locations in the Kingdom, and building a database utilized in the implementation of renewable energy projects, for the production of electricity and water desalination. Furthermore, benefits from the research aspects of the development of technologies and solutions appropriate to the atmosphere of the Kingdom and the variable climates of the different regions are being tapped into [212].

King Abdulla city works with many national entities such as King Abdulaziz City for Science and Technology, King Abdullah University of Science and Technology, Universities and Colleges, Technical and Vocational Training Corporation, Saudi Electricity Company, Saudi Electricity Transmission Company, Saline Water Conversion Corporation, Royal Commission for Jubail Yanbu, and other entities that are expected to be the biggest beneficiaries of renewable energy projects [213].

The Kingdom is currently witnessing a high demand from those wishing to invest in the renewable energy sector. This will be demonstrated by the number of companies that will bid for future tenders. The Ministry of Energy and Mineral Resources has issued a request for qualification for companies wishing to invest in this field. During 2017, 700 MW were launched to invest in renewable energy, which will be divided into many small projects, ranging from 50 to 100 MW. The number of projects started in 2017 is around ten [214].

The Electricity and Cogeneration Regulatory Authority issued the first license of its kind in Saudi Arabia for the Saudi Arabian Oil Company (Aramco) in Tarif province in the north of the Kingdom to engage in generating electricity using one of the forms of renewable energy, wind energy. In addition, Saudi Arabia is planning to become the largest market in the region over the next few years to produce solar energy. Riyadh has recently allocated about $108 billion to launch mega projects that are expected to provide vast amounts of electricity through solar power. Saudi Arabia will be able to operate high-capacity solar plants by 2032, which is supposed to meet more than 30% of the country's electricity needs. Experts confirm that despite the tremendous efforts made by Saudi Arabia through KACST and some Universities intending to making maximum use of solar energy; the results are satisfactory, with promising prospects [215].

One of the first solar energy projects in the Kingdom is being implemented in Wadi Hanifa (45 km north of Riyadh). The project is being implemented in two villages: Jubaila and Al-Swayha. The estimated cost of this project is about $16.5 million. The aim is to supply these vilages with electricity generated from solar energy, one of the most significant projects under the umbrella of the Saudi Solar Research Program (SOLERAS) [216].

The Kingdom's success in renewable energy projects, especially solar energy, ensures the country's national income is strengthened. Many energy scientists believe that the bright sun over the Empty Quarter can secure the world's energy needs. Although the solar projects are expensive, we have seen a significant drop in costs in recent times, which strengthens and helps to generate these projects, not only at the level of large companies, but also at the level of individuals and homes. It is expected that if the interest in solar energy in the Kingdom increases, production will increase and the surplus can be exported. If one gigawatt of electricity per hour is assumed, assuming that the profitability per kilowatt is only 2 US cents after removing all costs of producing and delivering this energy to customers, then the exclusive profitability of one gigawatt (equivalent to one million kilowatts) is US $149,328,000 [217].

These plans suffer from general obstacles related to solar cells and special problems related to conditions in the Kingdom. Among the specific obstacles of Saudi Arabia are: the availability of oil and its low cost compared to the generation of solar energy; the impact of dust can lead to a reduction of solar energy by between 10% and 20%; and government support for solar energy programs is insufficient and does not compare with the support provided to the oil and electricity sectors [218].

6.6 Jordan

The Hashemite Kingdom of Jordan is located between the latitudes 29° and 32° north, and between the longitudes 35° and 39° east. It borders Iraq to the west, the Syrian Arab Republic to the north, Palestine to the west, and Saudi Arabia to the south and east. The area of this country is 89.3 thousand km^2 [219]. Jordan has of a diverse geographical nature, with hills and mountains in the middle, and in the north is the plain of the Badia, which extends eastward towards Iraq and Saudi Arabia, while the Jordan River flowing through the fertile Jordan Valley forms the border of western Jordan. The Jordan River flows towards the Dead Sea, which is considered to be the lowest point in the world, with a depth of 400 m below sea level [220]. In the south, there is the port of Aqaba, which provides Jordan with access to the Red Sea. The capital of Jordan is Amman, with a population of 5.4 million (2003). Jordan is a young country with 40% of the population aged over 15 years and only 3% aged over 65 years. Jordan is administratively divided into eight central governorates: Balqa, Karak, Mafraq, Amman, Tafila, Zarqa, Irbid, and Ma'an [221].

Jordan has many natural resources such as phosphates, fertilizers, potash, agricultural products, and light industries. Climate is affected in most parts of the country by the Mediterranean Sea on the west and north and the desert on the east and south. This climate is hot and dry in the summer and mild and cold in the winter. Jordan is exposed to heat waves coming from the desert, as well as cold waves from Europe and Siberia. Winter usually lasts from mid-November to mid-March. Rainfall typically begins in October and ends in late April. The amount of rain varies from year to year, and rain is observed in the center of the country and eastern Aman the captal of Jordan. Snow usually falls in Aman in winter, falling from 1–3 days, but sometimes the number of days of snow falls days increases depending on the cold air fronts oming from Siberia [222, 223].

6.6.1 The State of Energy in Jordan

The increase in the population has occurred at a high rate as the economic conditions of the country improved since the 1990s, and have increased the demand for energy. This need has led to the import of large quantities of fuel from abroad as Jordan is poor in fossil fuel sources. Jordan relies heavily on the import of energy represented by crude oil and its derivatives, which constitute 95% of the commercial power consumed in Jordan [224]. The cost of imported fuel is a huge burden on the Jordanian economy. The steady increase in international oil prices has increased the burden on the state budget resulting from the value of subsidies for oil derivatives. The percentage of subsidies increased by (202.3%) in 2006 compared to the support in 2005. The ratio of the cost of the oil bill to the GDP has risen from 8.5% a year in 2000 to reach 18.8% in 2006.

Jordan needs large amounts of energy to meet its needs of economic and social growth. The energy demand will increase annually by up to 3% in general and 6% in electricity consumption in particular [225]. Table 6.11 shows the distribution of consumption on different sectors.

Table 6.11 Primary and final sectorial energy consumption, 2006 (000 toe)

Primary energy consumption		
Primary energy	Quantity of consumption	Rate of consumption (%)
Crude oil and oil products	4,952.6	68.9
Natural gas	2,003.5	27.9
Renewable energy	95	1.3
Imported and exported electricity	135.7	1.8
Total	7,186.8	100
Final sectorial energy consumption		
Sector	Quantity of consumption	Rate of consumption (%)
Transportation	1,822	37
Industry	1182	24
Domestic	1,064	22
Other services	621	17
Total	4,889	100

6.6.2 Electricity in Jordan

The history of the electricity industry in Jordan dates back to 1937 when the capital city of Amman agreed to replace the street lights of the town with 200 light bulbs from the Amman Company. The company leased a 70-horsepower engine from one of the mills to operate the mill during the day and light the streets at night. The Jordanian Electricity Authority was established by Law No. (21) in 1967 and amended to Law No. (16) in 1986 so that the Authority is responsible for the process of distributing energy to consumers and exporting them in Law No. 09 and importing them and monitoring the method of generating electricity [226]. The government interest in the electricity sector is growing, which has brought about much improvement. The new Electricity Law No. 10 of 1996 was issued, which resulted in the Jordanian Electricity Authority being transferred to a public joint stock company called the National Electricity Company, which is wholly owned by the Government. This is in addition to the presence of two other groups carrying out the transfer and distribution of electric power, namely the Jordanian Electricity Company and Irbid Electricity Company [227]. As a result of economic growth, Jordan witnessed an increasing demand for electricity consumption, which led to an increase in the quantities of production for this type of energy. In 2005, electricity production was 9,654 GW, which increased to 11,120 in 2006, an increase of 15.2%. Table 6.11 shows the quantity of electric power generated by type (C and O) for the years 2000–2006 [228] (Table 6.12).

Table 6.12 Electricity production by type (GWh) for the period 2001–2006

Type of generator	2001	2002	2003	2004	2005	2006
Steam	6240	6771	6430	7168	7524	5731
Diesel/gas	83	115	262	464	341	67
Natural gas	769	680	746	776	648	943
Diesel	1	3	1	1	2	4
Hydro units	43	53	41	53	57	51
Winf	3	3	3	3	3	3
Biogas	5	5	6	6	5	6
Compound cycle	0	0	0	0	558	3,841
Electricity	7,144	7,630	7,489	8,471	9,138	10,646
Industry	405	502	505	496	516	474
Steam	364	434	428	422	445	446
Diesel	41	68	77	74	71	28
Total	7,549	8,132	7,994	8,967	9,654	11,128

6.6.3 Electrical Connection

The energy generated in Jordan is not sufficient to cover the maximum load in the standard electrical system. Therefore, the Jordanian government imported part of the electric power from Egypt and Syria through a process of connecting the electricity between the Eastern and Western countries [229]. The past three decades have witnessed significant achievements in the development of the electricity sector in the Arab countries, to keep pace with the increase in electricity consumption of about 20 times. Thus, the Arab countries met these requirements by increasing the total generation capacity to about ten times what it was during 1975, raising the efficiency of generation and reducing the losses in transport and distribution networks significantly [230].

The work on the electric link project between Jordan and Egypt started in 1998, where the project included the establishment of an antenna of three phases with 500 kV link between the Egyptian and Jordanian networks in 1999. This line crosses from Suez to the Egyptian border in Taba, and a 400 kV sea cable, with a length of 13 km, to the Gulf of Aqaba passes at a depth of 850 m to the point of connection to the Jordanian network at 400 kV. In addition to the transformer stations established in Suez and Taba [231], the connection between Jordan and Syria was implemented in 2001, to exchange energy between the two sides at a rate of 03/400 KV [232].

As a result of the increase in the population in Jordan, as well as the economic growth, consumption increases year after year. In 2006 the Kingdom consumption of fuels amounted to 7,187 thousand tons, with an increase of 2.3% over 2005. In the same period, the consumption of the electricity generation sector for fuel increased by 13.8% in 2006 compared to 2005, with the consumption quantity reaching 2,724 thousand CM in 2006. Electricity consumption was 8,712 (GWS) in 2005, rising to 9,593 GW in 2006, an increase of 10.1% over 2005 [233]. Figure 6.6 shows the distribution of electricity consumption across different sectors of the country

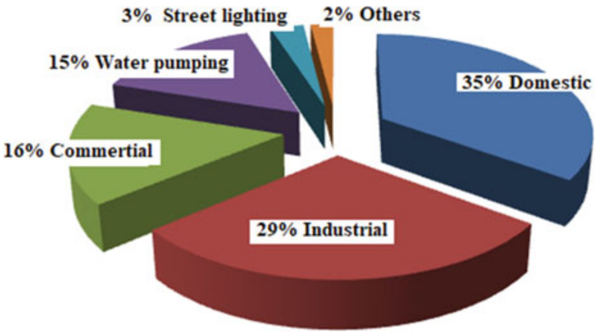

Fig. 6.6 Sectorial distribution of electricity consumption (GW/h.) for 2006

The per capita consumption of electricity consumed has also increased, and its share of total energy consumption has increased as a result of the increase in population and increased consumption of primary energy and use of electricity [224].

The Jordanian government has studied the future demand for petroleum derivatives and electric power using mathematical models that take into account the relationship between demand for energy and petroleum products on the one hand, and other significant variables such as income and population growth and prices on the other hand.

The enormous burden on Jordan's national economy requires the implementation of a strategy and an efficient energy sector the aim of which is to provide energy at the lowest cost [234]. This will reduce the burden on the economy by improving the efficiency of energy consumption by using the best possible means and obtaining the maximum potential return, by reducing and minimizing waste and improving technologies without affecting living standards and production [235].

Increasing energy efficiency awareness is a continuous process that can be achieved through the use of active means of education. In some countries, energy conservation studies indicate the possibility of improving energy efficiency by up to 15% during the first 5 years of rationalization programs at an annual rate of 3%. Work is underway in Jordan to exploit all possible sources of primary energy with the least cost and impact on the environment [235].

6.6.4 Renewable Energies in Jordan

Renewable sources of energy are permanent and immortal natural resources, available and continuously renewable as long as life exists. This type of power is characterized by the availability of local energy. They are environmentally sound and do not cause the emission of harmful gases in the air. There is no centralization and they are used independently of the grid to allocate energy [236].

Table 6.13 Local production of renewable energies (toe) for the period 2000–2006

Year	Hydro	Wind	Solar	Bio	Total
2000	3,353	258	65	258	3,934
2001	3,697	258	65	430	4,450
2002	4,557	258	65	430	5,310
2003	3,525	258	65	516	4,364
2004	4,557	258	65	516	5,396
2005	4,901	258	65	430	5,656
2006	4,385	258	65	516	5,254

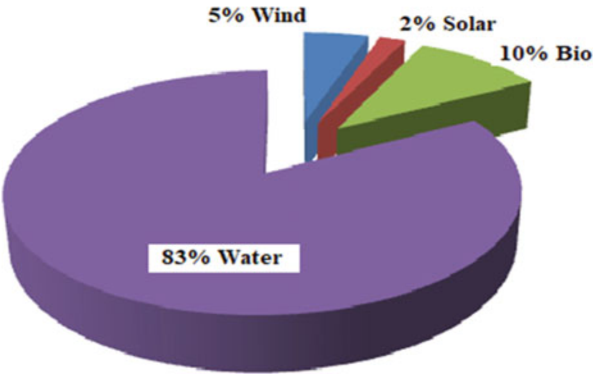

Fig. 6.7 The percentage of contribution of variable sources in power generation for 2006

Some of the most important sources of new and renewable energy in Jordan are solar energy, wind energy, bioenergy, and watercourses, which is the most abundant renewable and new energy producer in Jordan; the least is solar. The volume of energy produced in 2006 from the water sources was 4,385 nm with a rate of 83.5%, while the solar power provided in the same year was 95 mt, 1.8%. Waterfalls are one of the best sources of new, renewable, and clean energy. Hydropower accounts for 17% of the world's total electricity production. Table 6.13 shows local production of renewable energy for the years 2000–2006 while Fig. 6.7 represents a plan for the contribution of renewable energies to energy production for 2006 [237].

Jordan is a pioneer in the use of renewable energy despite the difficulties and obstacles that have accompanied the process of starting the implementation of renewable energy projects, whether legislative or societal, in accepting the idea of switching from traditional to alternative energy. In the renewable energy field, there are projects that generate about 1,000 MW that are being implemented by both the private sector and the state. The government is expected to submit the "green corridor tender," which links the south of the kingdom, before the end of the year [238].

In past years, the Jordanian government has shifted from the use of diesel and heavy fuel to the use of gas, as 85% of the generation of electricity from liquefied gas, which reduced the cost of the energy bill and reduced pollution from power plants. Jordan has not left a source of conventional or renewable energy but sought to use and invest in it to enhance the performance of the domestic energy sector, from the use of wind and solar power, even oil shale, and uranium, to essential projects [238].

The most recent Jordanian projects in this regard are the "Shams Maan" project, with a Jordanian-Qatari Jordanian investment of over $170 million. It was implemented by an energy consortium comprising Jordanian, Japanese and Qatari companies. This project is the most extensive project of its kind in the Middle East in the field of clean energy and has significantly benefited from the Japanese experience in solar energy for its success in the areas of technology, cars, and architecture [239]. The idea of the project is to utilize solar power through 600,000 panels in the southern city of Ma'an, which has the highest solar brightness throughout the year in Jordan. According to survey studies, the average solar brightness to the town is 286 days per year, with a radiation rate of up to 2,000 MW/m per hour. The daily electricity production value of the project will be 52 MW hours [240].

The investment environment of Jordan has the necessary elements for the success of local and foreign private sector investments. This is a safe, stable country with a strategic location in the region. It is also a model country for crossing energy projects in its territory to neighboring countries such as oil and gas pipelines [241]. The government has also signed an agreement to connect a 17 MW solar power project in the Rashadiyah area. In addition, the Jordanian government has launched several tenders for the implementation of solar and wind power plants, such as the 50 MW solar power generation project for each project in Mafraq [242].

The government planned that the renewable energy share of the total energy mix would not exceed 6% by 2016. The national strategy issued in 2007 approved the introduction of renewable energy as one of the leading sources of electricity generation [243]. The goal was to reach 7% as a contribution in the total energy mix in 2015 and 10% in 2020. If this ratio reflects electricity generation, then we are talking about 16% in 2015 and 27% of electricity generated in 2020. The Jordanian government has failed to make any significant progress in the field of energy efficiency and investment in renewable energy until 2017 and still relies on oscillatory sources such as Egyptian gas with the frequent interruption of supplies from the Egyptian side [244]. The achievements of the government in field of renewable energy for the period 2007–2010 have been quite slow, as there were many obstacles to investment in renewable energy projects. These barriers include the lack of legislation at the time, and because the investment law was not enough to attract investments. The government issued the regulation of renewable energy and rationalization in 2010 as a temporary law, released in 2012 as a permanent law. Al-Rabadi explained that the Renewable Energy Projects Law No. 13 of 2012 allowed for dealing with this file in three ways. The first is direct bids made by the Ministry of Energy and Mineral Resources through offering the tender and specifying the conditions for it within the technical capabilities available in the electrical grid without any reinforcements. Which is what happened in the first round of direct offers, the focus was on the south to absorb up to 200 MW in the system [245].

The approach to renewable energy will not take place overnight, but the aim is to phase out fossil energy. The cost of solar and wind power is reasonable today.

"The future of energy in Jordan" shows that 100% renewable energy dependence by 2050 provides about $80 billion in renewable energy (or $12 billion in value standards today) and produces 30,000 new jobs [246].

The United Nations High Commissioner for Refugees (UNHCR) has operated the newly constructed solar power plant at the Al-Azraq refugee camp, which opened in Jordan in 2014 to receive Syrian refugees. The Ikea's "Brighter Life for Refugees" campaign funded a solar power plant that secured renewable energy for people who had been living for 2 and a half years with only intermittent access to electricity. The station will contribute to Jordan's national energy strategy to reach a green economy by 2020 [247].

The 2 MW solar photovoltaic plants will allow the Commission to provide sustainable power to 20,000 Syrian refugees living in some 5,000 shelters in Al-Azraq camp, which will meet the energy needs of the village connected to the national grid. Every family can now operate a refrigerator, television, fan, shelter light, and phone charger, which is crucial for refugees to keep in touch with their relatives abroad. The solar power plant will provide $1.5 million per year and reduce carbon dioxide emissions by 2,370 tons per year. When the capacity of the solar power plant is raised from 2 to 5 MWs and is fully operational, these savings will increase, CO_2 emissions will decrease, and all energy-related needs will be met at the Blue Camp. As the camp is connected to the national grid, the community will benefit from any additional generation of electricity free of charge, which will support its needs [248].

A Saudi company has also begun to set up solar and renewable power plants in Egypt and Jordan. Today, the company is building two power plants using solar power in Jordan with a capacity of 23 MW, and the second with a capacity of 10 MW, and it was expected to complete the first station in the city of Aqaba in the fourth quarter of the year 2015 [249, 250].

Perhaps the most critical challenge facing Jordan in the field of renewable energy is the lack of "stability legislation," because of its impact on the confidence of investors. Valtalimat customs exemptions and other factors that relate to renewable energy law have not yet been set out. The expansion of customs and tax exemptions to all energy-saving systems is significant in increasing national and foreign investments in the renewable energy sector [251].

It is essential to learn from the experience of other countries not to put restrictions on the spread of renewable energy. Renewable energy has two advantages: reducing the oil bill and reducing the investment volume required by the government [254]. In most energy-related cases, the investor and the consumer are the citizens, which means exempting the state from investments that it had to comply with or at least "insure the investor" so that it becomes a burden on the state's overall financial situation [255, 256]. The Jordanian government should start enacting legislation that pushes for the use of renewable energy or energy conservation. Badran said that it is still "modest" to a large extent [257]. For example, what prevents us from providing each school with solar energy, which operates during the day?

References

1. The Committee Office, House of Commons. Select Committee on Foreign Affairs, Eighth Report, Iran. Publications.parliament.uk
2. Iran @ 2000 and Beyond lecture series, opening address, W. Herbert Hunt, 18 May 2000. Retrieved 1 Oct 2007
3. CIA World Factbook. Iran. Aug 2012
4. SurfWax: News, Reviews and Articles on Hindu Kush. News.surfwax.com. June 2011. Nature & Mountains of Iran
5. Nature & Mountains of Iran. Retrieved 25 Feb 2008. Archived 22 at the Wayback Machine
6. Iran-Current Information. My.simmons.edu. June 2011
7. Guggisberg CAW (1961) Simba: the life of the lion. Howard Timmins, Cape Town
8. Shahinzadeh H, NajafAbadi MM, Hajahmadi M, Paknejad A (2013) Technical and economic study for use the photovoltaic systems for electricity supply in Isfahan Museum Park. Int J Sci Technol Res 2(1):1–9
9. U.S. Central Intelligence Agency (2008-04-15). CIA – The World Factbook – Iran. U.S. Central Intelligence Agency
10. CIA.gov Iran – U.S. Energy Information Administration (EIA)
11. American Journal of Scientific Research. ISSN 1450-223X. Issue 45 (2012), pp 76–84 (PDF)
12. The EU should be playing Iran and Russia off against each other, by Julian Evans, Eurasian Home, 8 Nov 2006
13. Kim Murphy – Los Angeles Times (7 January 2007). U.S. targets Iran's vulnerable oil. Heraldextra.com
14. Iran, Besieged by Gasoline Sanctions, Develops GTL to Extract Gasoline from Natural Gas. Oilprice.com.
15. Iran, Library of the Congress. https://www.loc.gov/collections/country-studies/about-this-collection/
16. http://www.alalam.ir/news/1435182
17. Motavaselian AM, Faghih Khorasani AR Iran's participatory power market regarding distributed generation from renewable sources: a case study. European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ) International Conference on Renewable Energies and Power Quality (ICREPQ'12) Santiago de Compostela (Spain), 28–30 Mar 2012
18. Climate policy and sustainable development: opportunities for Iranian – German Cooperation case study: solar thermal energy in Iran saving energy, realising net economic benefits and protecting the environment by investing in energy efficiency and renewable energies – Executive Summary -May 2005 The study is a result of a joint German-Iranian project that was funded by the Heinrich Böll Foundation. Center for Environment and Energy Research and Studies
19. Energy Balance of Iran 2009, Ministry of Energy, Tehran (2010). http://isn.moe.org.ir
20. Solar PV Roadmap targets, International Energy Agency (2010). http://www.iea.org/publications
21. Technology Roadmaps: Solar photovoltaic energy, International Energy Agency (2010). http://www.iea.org/publications
22. Salmani A, Sadeghzadeh S, Naseh MR (2014) Optimization and sensitivity analysis of a hybrid system in KISH_IRAN. Int J Emerg Technol Adv Eng 4(1):349–355
23. http://www.alalam.ir/news/1434626
24. http://www.alalam.ir/news/754234
25. http://www.alalam.ir/news/746254
26. Energy Balance Sheet. Department of Electrical and Energy Department of Energy Ministry; 2007
27. http://www.suna.org/

28. www.suna.ir (Wind office-Renewable Energies Office-Ministry of Energy-Islamic Republic of Iran)
29. Fadai D, Esfandabadi ZS, Abbasi A (2011) Analyzing the causes of non-development of renewable energy-related industries in Iran. Renew Sust Energ Rev 15:2690–2695
30. Shen Y-C, Lin GTR, Li K-P, Yuan BJC (2010) An assessment of exploiting renewable energy sources with concerns of policy and technology. Energy Policy 38:4604–4616
31. Dehghani AA (2011) Status and potentials of renewable energies in Yazd Province-Iran. Renew Sust Energ Rev 15:1491–1496
32. Asl-Soleimani E, Farhangi S, Zabihi MS (2001) The effect of tilt angle, air pollution on performance of photovoltaic systems in Tehran. Renew Energy 24:459–468
33. Kick C (2011) How is 100% renewable energy possible for Turkey by 2020?, Global Energy Network Institute (GENI) report
34. National Geographic (1999) Atlas of the world, 7th edn. National Geographic, Washington, DC. ISBN 0-7922-7528-4
35. Sharon RS, Gregory M The Oxford handbook of ancient Anatolia: (10,000–323 BC). Oxford University Press, UK. pp 3–11, 37. ISBN 978-0-19-537614-2
36. Bank A, Karadag R (2012) The political economy of regional power: Turkey under the AKP. GIGA Research Unit: Institute of Middle East Studies
37. Bugra A (2003) The place of the economy in Turkish society. South Atlantic Q 102 (2–3):453–470
38. Nas TF (1992) Economics and politics of Turkish liberalization. Lehigh University Press, USA, p 12. ISBN 0-934223-19-X
39. Macovei M Growth and economic crises in Turkey: leaving behind a turbulent past? Directorate-General for Economic and Financial Affairs Publications, Economic Papers 386, Oct 2009
40. Baris K, Kucukali S (2010) Availability of renewable energy sources in Turkey: current situation, potential, government policies and the EU perspective. Energy Policy 42:377–391
41. Çapik M, Yılmaz A, Çavuşoğlu I (2012) Present situation and potential role of renewable energy in Turkey. Renewable Energy 46:1–13
42. Dagıstan H (2009) New developments and investment opportunities. Geothermal energy in ECA countries
43. https://pangea.stanford.edu/ERE/pdf/IGAstandard/GeoFund/Turkey2009/2._dagistan
44. Lynch R (2005) An energy overview of the Republic of Turkey. Fossil Fuels International. Available at: https://www.geni.org/globalenergy/library/national_energy_grid/turkey/EnergyOverviewofTurkey.shtml
45. http://www.geni.org/globalenergy/library/national_energy_grid/turkey/EnergyOverviewofTurkey.shtml
46. 12-General Directorate of Electrical Power Resources Survey and Development Administration, Turkey energy efficiency report – 20% reduction in primary intensity by 2023, 2011
47. Ozturk K, Yilanci A, Atalay O (2007) Past, present and future status of electricity in Turkey and the share of energy sources. Econ Papers
48. http://www.tradingeconomics.com/turkey/fossil-fuel-energy-consumption-percent-of-total-wb-data.html
49. Kaygusuz K (2002) Renewable and sustainable energy use in Turkey: a review. Renew Sust Energ Rev 6(4):339–366
50. Kaygusuz K (2002) Environmental impacts of energy utilization and renewable energy policies in Turkey. Energy Policy 30:689–698
51. MENR, Ministry of Energy and Natural Resources. Energy report of Turkey in 2008. Available from http://www.enerji.gov.tr
52. IEA, International Energy Agency (2010) Energy policies of IEA countries: Turkey 2009 review. IEA/OECD, Paris
53. WECTNC, World Energy Council Turkish National Committee Energy report of Turkey for 2007–2008. WECTNC, Ankara

54. Kaygusuz K, Kaygusuz A (2004) Geothermal energy in Turkey: the sustainable future. Renew Sust Energ Rev 8:545–563
55. Herzog AV, Lipman TE, Kammen DM (2004) Renewable energy sources. Available at: http://www.eolss.com
56. http://www.eolss.com.http://www.inference.phy.cam.ac.uk/sustainable/refs/geothermal/sdarticle.pdf
57. Serpen U, Aksoy N, Öngür T (2011) 2010 Present status of geothermal energy in Turkey. Spaven Thomson, Gasification
58. http://www.thompsonspaven.com/acatalog/gasification.html
59. Yuksel I, Yuksek O, Onsoy H (2005) An analysis of production hydroelectric energy in the Eastern Black Sea Region's Streams. In: International symposium water for development worldwide, Istanbul, Turkey, 7–11 Sept 2005, pp 115–123
60. Askar D (2013) Optimization of energy conversion technologies in Turkey between 2010–2025, Erasmus Mundus masters in complex systems science
61. Dursun B, Gokcol C (2011) The role of hydroelectric power and contribution of small hydropower plants for sustainable development in Turkey. Renew Energy 36:1227–1235
62. Sagbas A, Karamanlioglu T (2011) A study on potential and utilization of renewable energy sources in Turkey. Paper presented at 6 th international advanced technologies symposium. Elazig, Turkey, 16–18 May 2011
63. Yüksek O, Kankal M, kömürcü MI, Önsoy H, Akpinar A (2006) The importance of hydro-power plants in Turkey's energy planning. International Congress on River Basin Management
64. Turkish Statistical Institute, Prime Ministry, Republic of Turkey (2011). Address based population registration system results of 2010. Retrieved from http://www.turkstat.gov.tr/PreHaberBultenleri.do?id=8428
65. Bakir NN (2005) Turkey's hydropower potential and review of electricity generation policies from EU perspective. http://www.ere.com.tr
66. Akova I (2011) Development potential of wind energy in Turkey, EchoGeo. http://echogeo.revues.org/12457
67. General Directorate of Electrical Power Resources Survey and Development Administration, Facts and News from EIE/TU, March 2007–February 2010. http://www.enrnetwork.org/assets/files/enr_management/facts_and_news/M48_facts_and_news/EIE_Facts&News_M48.pdf
68. Gençer C, Gürkan SAS (2010) Wind energy potential in Turkey. http://iats09.karabuk.edu.tr/press/bildiriler_pdf/IATS09_03-01_1454
69. Demirbaş A (2006) Production potential of electricity from biomass in Turkey. Biotechnology. http://www.eolss.net/Sample-Chapters/C17/E6-58-06-16
70. IEA (International Energy Agency) (2001) Energy policies of IEA countries, Turkey 2001 review. IEA/OECD, Paris
71. Kaygusuz K (2001) Hydropower and biomass as renewable energy sources in Turkey. Energy Sources 23:775–799
72. Dinçer F (2011) Overview of the photovoltaic technology status and perspective in Turkey. Renew Sust Energy 15:3768–3779
73. http://econpapers.repec.org/article/eeerensus/v_3a15_3ay_3a2011_3ai_3a8_3ap_3a3768-3779.htm
74. Suri M, Huld TA, Dunlop ED, Ossenbrink HA (2007) Potential of solar electricity generation in the European Union member states and candidate countries. Sol Energy 81:1295
75. Çağlan Kuyumcu Ö, Solaroğlu UZD, Akar S, Serin O, BM Holdings Inc., Ankara, Turkey Hybrid geothermal and solar thermal power plant case study; GÜMÜSKÖY GEPP., GHC BULLETIN, Jan 2013
76. Stritih U, Ostermana E, Evliya H, Butala V, Paksoy H (2013) Exploiting solar energy potential through thermal energy storage in Slovenia and Turkey. Renew Sust Energ Rev 25:442–461

77. Bavbek G (2015) Solar photovoltaic market in Turkey: prospects and challenges, EDAM Climate Action Paper Series 2015/1
78. Syrian Meteorological Dept., Wind Atlas in Syria Arabic Republic, Damascus, 1998
79. Abdul Rabboh R Water demand management in Syria. Presented in workshop of water demand management in Mediterranean, progress and policies, Saragossa, 19–21 Mar 2007
80. Akanda A, Freeman S, Placht M (2007) The Tigris – Euphrates river basin: mediating path towards regional water stability
81. Central Bureau of Statistics (CBS) (2006) Statistical abstract 2005. Damascus
82. https://www.enabbaladi.net/archives/63754#ixzz4wmaXqtZC
83. Shaaban FS (2010) Geography of electric energy in Syria and its role in regional development. MSc Thesis, Eyn Shams University, Egypt
84. International Energy Agency, Implementing Agreement on Photovoltaic Power Systems, 16 case studies on the deployment of photovoltaic technologies in developing countries, Sept 2003
85. Al-Karaghouli A (2007) Current status of renewable energies in the Middle East – North African Region. UNEP/ROWA
86. Bryden J, Riahi L, Zissler R Renewables Status Report, MENA 2013
87. Böhmer A, MENA-OECD Investment Program Unit Key lessons from selected economic zones in the MENA region. Power Point presented at First Meeting of the Working Group on Investment Zones in Iraq, Amman, Jordan, 29–30 Mar 2011.
88. Burger S The emerging opportunities in Saudi Arabia's solar market. GreenTechMedia.com. 5 Mar 2013
89. Todorova V Dubai set to go from 4.5MW to 1,000MW by 2030. The National, 20 Dec 2012. at www.thenational.ae
90. Muirhead J MENA CSP: is local content the answer? CSP Today, 8 Feb 2013. at social.csptoday.com
91. UNDP. Human development reports 2003: Syria
92. http://hdr.undp.org/statistics/data/cty/cty_f_LBN.html
93. World Bank (2002) World development indicators: Syria at a glance
94. www.worldbank.org/data/countrydata
95. Hamzeh A Renewable energy and its future application in Syria. In: Proceedings of 7th Arab energy conference, country paper of SAR, pp 88–102, Cairo, 11–14 May 2002
96. Hamzeh A Overview of the Syrian energy profile. Beirut regional collaboration workshop on energy efficiency and renewable energy technology, Beirut, Lebanon, 26–30 Apr 2004
97. Badawi M Electricity landscape and market globalization: options and challenges for the Arab world. world energy council 18th congress, Buenos Aires, Oct 2001
98. Chedid R, Chaaban F (2003) Renewable energy development in Arab countries: a regional perspective. J Appl Energy 74(1–2):211–220
99. Energy Information Administration (EIA). International Energy Outlook 2011. Washington, DC 20585. US. http://www.eia.gov/forecasts/ieo/index.cfm. Retrieved May 2013
100. Environmental Protection Agency (EPA). Global Greenhouse Gas Emissions Data Washington, DC, 20460. US. http://www.epa.gov/climatechange/ghgemissions/global.html. Retrieved May 2013
101. Hamzeh A Analysis of five-year operation of Albaath wind turbine generator in Syria. In: 2001 European wind energy conference and exhibition, Copenhagen, Denmark, 2–6 July 2001
102. Hamzeh A (2002) Wind as an alternative source of electrical energy in Syria. In: The world wind energy conference, Berlin
103. Energy: a key sector for the Mediterranean partner countries. KS-SF-09-057-EN-N. ISSN 1977- 0316. European Communities, 2009
104. Arab Monetary Fund (AMF), Joint Arab Economic Report, Abu Dhabi, 2005
105. Power India and Ministry of Electricity, National renewable energy master plan, 2001
106. ESCWA, UNEP/ROWA, OAPEC, LAS, Energy for sustainable development in the Arab region: a framework for action, 2002
107. United Nations Environment Program (UNEP)/ROWA, Current Status of Renewable Energies in the Middle East – North African Region, 2007

108. Wupp.ertal Institute for Climate, Environment and Energy, Promoting Renewable Energy Technologies in Developing Countries through the Clean Development Mechanism, Wupp. ertal, 2007
109. Mousavi SMH, Warkozak H, Al-Ahmad M (2011) Economic comparison for feeding Isolated load using PV-Battery or Fuel cells. Damascus Uni J 27(1):45–55
110. OECD (2013). Renewable energies in the Middle East and North Africa: policies to support private investment. OECD, Paris
111. OME (2012) Solar thermal in the Mediterranean Region: market assessment report. Observatoire Méditerranéen de l'Energie. Observatoire Méditerranéen de l'Energie, Nanterre, France
112. Hamzeh A (1995) Experience with stand-alone centralized and individual house PV systems in Syria. Renew Energy 6(5–6):545–548. Elsevier Science Ltd, UK
113. Muala A The oil in Syria. In: Symposium on electrical energy in Syria, Atomic Energy Association, Damascus 14.12.2003
114. Hamzeh A (1995) Experience with stand-alone centralized and individual house PV systems in Syria. Renew Energy 6(5–6):545–548
115. Al Nashmi E, Cleary J, Molleda J-C, McAdams M (2010) Internet political discussions in the Arab world: A look at online forums from Kuwait, Saudi Arabia, Egypt and Jordan. Int Commun Gaz 72(8):719–738
116. Khalaf FI, Al-Saleh S, Al-Houty F, Ansari L, Shublaq W (1979) Mineralogy and grain size distribution of dust fallout in Kuwait. Atmos Environ (1967) 13(12):1719–1723
117. Almusallam B, Magalhaes R (2010) Organisational evolution in Kuwait: a comparative study of the evolution of two Islamic finance companies. J Int Bus Entrep Dev 5(1):77–99
118. Casey MS (2007) The history of Kuwait. Greenwood Press, Westport
119. Algharib SM (2008) Spatial patterns of urban expansion in Kuwait city between 1989 and 2001. MSc Thesis, Kent State University
120. Abo Aysh A (1981) Planning for cities development in Kuwait. Geographic massages 33
121. Al-khuzamy A (2001) Automated cartographic molding of the urban development in Kuwait. Geographic massages 257
122. Kwarteng AY, Chavez PS (1998) Change detection of Kuwait City and environs using multi-temporal landsat Thematic Mapper data. J Remote Sens 19(9):1651–1662
123. Kazem AA, Chaichan MT, Kazem HA (2014) Effect of dust on photovoltaic utilization in Iraq: review article. Renew Sust Energy Rev 37(September):734–749
124. Khalaf FI, Al-Ajmi D (1993) Aeolian processes and sand encroachment problems in Kuwait. Geomorphology 6(2):111–134
125. Al-Qunaibet MH, Johnston RS (1985) Municipal demand for water in Kuwait: methodological issues and empirical results. Water Resour Res 21(4):433–438
126. Darwish MA, Al-Awadhi FM, Darwish AM (2008) Energy and water in Kuwait Part I. A sustainability view point. Desalination 225(1–3):341–355
127. Alnaser WE, Alnaser NW (2011) The status of renewable energy in the GCC countries. Renew Sust Energ Rev 15(6):3074–3098
128. Al-Marafie AMR, Suri RK, Maheshwari GP (1989) Energy and power management in air-conditioned buildings in Kuwait. Energy 14(9):557–562
129. Ferroukhi R, Ghazal-Aswad N, Androulaki S, Hawila D, Mezher T (2013) Renewable energy in the GCC: status and challenges. Int J Energy Sect Manage 7(1):84–112
130. Alotaibi S (2011) Energy consumption in Kuwait: prospects and future approaches. Energy Policy 39(2):637–643
131. Darwisha MA, Al-Awadhi FM, Akbar A, Darwish A (2009) Alternative primary energy for power desalting plants in Kuwait: the nuclear option I. Desalin Water Treat 1(1–3):25–41
132. Wood M, Alsayegh OA (2014) Impact of oil prices, economic diversification policies and energy conservation programs on the electricity and water demands in Kuwait. Energy Policy 66:144–156

133. Nagy Eltony M, Hoque A (1996) A cointegrating relationship in the demand for energy: the case of electricity in kuwait. J Energy Dev 21(2):293–302
134. Nagy Eltony M (1995) The sectoral demand for electricity in Kuwait. OPEC Energy Rev 19 (1):37–44
135. Squalli J (2007) Electricity consumption and economic growth: bounds and causality analyses of OPEC members. Energy Econ 29(6):1192–1205
136. Al-Nassar W, Alhajraf S, Al-Enizi A, Al-Awadhi L (2005) Potential wind power generation in the State of Kuwait. Renew Energy 30(14):2149–2161
137. Al-Faris ARF (2002) The demand for electricity in the GCC countries. Energy Policy 30 (2):117–124
138. Burney NA, Al-Matrouk FT (1996) Energy conservation in electricity generation: a case study of the electricity and water industry in Kuwait. Energy Econ 18(1–2):69–79
139. Nagy Eltony M, Hajeeh M (1999) Electricity demand by the commercial sector in Kuwait: an econometric analysis. OPEC Energy Rev 23(1):23–32
140. BuShehri MAM, Wohlgenant MK (2012) Measuring the welfare effects of reducing a subsidy on a commodity using micro-models: An application to Kuwait's residential demand for electricity. Energy Econ 34(2):419–425
141. Al-Hasan AY (1997) Electricity generation cost between proposed photovoltaic station and conventional units in Kuwait. Renew Energy 12(3):291–301
142. Burney NA (1998) Economies of scale and utilization in electricity generation in Kuwait. Appl Econ 30(6):815–819
143. Qader MR (2009) Electricity consumption and GHG emissions in GCC countries. Energies 2 (4):1201–1213. https://doi.org/10.3390/en20401201
144. Ferguson R, Wilkinson W, Hill R (2000) Electricity use and economic development. Energy Policy 28(13):923–934
145. Ayyash S (1983) Power needs of cooling systems in Kuwait and their effects on the utility. Appl Energy 13(2):109–120
146. Narayan PK, Smyth R, Prasad A (2007) Electricity consumption in G7 countries: a panel cointegration analysis of residential demand elasticities. Energy Policy 35(9):4485–4494
147. García-Rodríguez L (2002) Seawater desalination driven by renewable energies: a review. Desalination 143(2):103–113
148. Doukas H, Patlitzianas KD, Kagiannas AG, Psarras J (2006) Renewable energy sources and rationale use of energy development in the countries of GCC: myth or reality? Renew Energy 31(6):755–770
149. El-Dessouky H, Al-Juwayhel F (1997) Effectiveness of a thermal energy storage system using phase-change materials. Energy Convers Manag 38(6):601–617
150. Reiche D (2010) Energy Policies of Gulf Cooperation Council (GCC) countries—possibilities and limitations of ecological modernization in rentier states. Energy Policy 38(5):2395–2403
151. Bhutto AW, Bazmi AA, Zahedi G, Klemeš JJ (2014) A review of progress in renewable energy implementation in the Gulf Cooperation Council countries. Journal of Cleaner Production 71:168–180
152. Abdullah AH, Ghoneim AA, Al-Hasan AY (2002) Assessment of grid-connected photovoltaic systems in the Kuwaiti climate. Renew Energy 26(2):189–199
153. Al-Maamary HMS, Kazem HA, Chaichan MT (2016) Changing the energy profile of the GCC states: a review. Int J Appl Eng Res 11(3):1980–1988
154. Handy H (2008) Tracking GCC foreign investments: how the strategies are changing with markets in turmoil. SAMBA Financial Group, Riyadh, p 6
155. Nematollahi O, Hoghooghi H, Rasti M, Sedaghat A (2016) Energy demands and renewable energy resources in the Middle East. Renew Sust Energ Rev 54:1172–1181
156. Al-Hasan Y, Ghoneim AA, Abdullah AH (2004) Optimizing electrical load pattern in Kuwait using grid connected photovoltaic systems. Energy Convers Manag 45(4):483–494
157. Ramadhan M, Naseeb A (2011) The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait. Renew Energy 36(4):1272–1276

158. Absi Halabi M, Al-Qattan A, Al-Otaibi A (2015) Application of solar energy in the oil industry—current status and future prospects. Renew Sust Energ Rev 43:296–314
159. Nayef M Renewable energy at Kuwait Great Burgan oil field. Paper no. SPE 164169-MS presented at 18th Middle East oil & gas show and conference (MEOS). Bahrain International Exhibition Centre, Manama, Bahrain; 10–13 Mar 2013
160. IRENA Solar photovoltaics—renewable energy technologies: cost analysis series. (Available at). Int Renewable Energy Agency June 2012;1(4/5). Accessed on 22/8/2014
161. Chauvin D, Depraz S, Buckley H Saving energy in the oil and gas industry. In: SPE international conference on health, safety, and environment in oil and gas exploration and production, paper no.: SPE 111937, Nice, France, 15–17 Apr 2008
162. AlBusairi HA, Möller HJ Performance evaluation of CdTe PV modules under natural outdoor conditions in Kuwait. In: 25th European Photovoltaic Solar Energy Conference and Exhibition/5th World Conference on Photovoltaic Energy Conversion, Valencia, Spain, 6–10 Sept 2010
163. AlBusairi H, AlKandari A (1987) Performance evaluation of Photovoltaic modules in Kuwait. In: Proceedings of International PVSEC-3, pp 323–326
164. Said SAM (1990) Effects of dust accumulation on performances of thermal and photovoltaic flat-plate collectors. Appl Energy 37(1):73–84
165. Ghoneim A (2006) Design optimization of photovoltaic powered water pumping systems. Energy Convers Manag 47(11–12):1449–1463
166. al-Rasheed M (2010) A history of Saudi Arabia, 2nd edn. Cambridge University Press, Cambridge
167. AlNafie AH (2008) Phytogeography of Saudi Arabia. Saudi J Biol Sci 15(1):159–176
168. Savran N (1988) Saudi Arabia: the ceaseless quest for security. Cornell University Press, London
169. High Commission for Development of Riyadh (HCDR) (2001) Population growth and immigration to Riyadh. ArRiyadh Development Authority, Riyadh
170. Almazroui M (2006) The relationship between atmospheric circulation patterns and surface climatic elements in Saudi Arabia, PhD thesis, Climate Research Unit, University of East Anglia
171. Ziehr C (2005) Fundamental of geography. Education course, Northeastern State University. http://arapaho.nsuok.edu/ziehr/courses/geog2243/Urban_Accessibility.htm Accessed 2005
172. Al-Ahmadi K, See L, Heppenstall A, Hogg J (2009) Calibration of a fuzzy cellular automata model of urban dynamics in Saudi Arabia. Ecol Complex 6:80–101
173. Abdullah MA, Al-Mazroui MA (1998) Climatological study of the southwestern region of Saudi Arabia. I. Rainfall analysis. Clim Res 9:213–223. Hamdan A (2005) Women and education in Saudi Arabia: Challenges and achievements. Int Educ J 6(1):42–64
174. UNDP (2003) Saudi Arabia: women in public life. In United Nations Development Programme. Program on governance in the Arab Region. [Online] http://www.undpp.ogar.org/countries/saudi/gender.html. 12 Nov 2003
175. Arab News (2008) UNWTO invites Saudi Arabia to run its Capacity Building Programme Initiative. Arab News 17 April. http://www.arabnews.com. Accessed 30 Nov 2008
176. EIU (2008) Saudi Arabia country profile. Economist Intelligence Unit, London
177. Alkolibi FM (2002) Possible effects of global warming on agriculture and water resources in Saudi Arabia: impacts and responses. Clim Chang 54:225–245
178. Petraglia MD, Alsharekh AM, Crassard R, Drake NA, Groucutt H, Parker AG, Roberts RG (2011) Middle Paleolithic occupation on a Marine Isotope Stage 5 lakeshore in the Nefud Desert, Saudi Arabia. Quat Sci Rev:1–5. https://doi.org/10.1016/j.quascirev.2011.04.006
179. Almazroui M, Nazrul Islam M, Athar H, Jones PD, Ashfaqur Rahm M (2012) Recent climate change in the Arabian Peninsula: annual rainfall and temperature analysis of Saudi Arabia for 1978–2009. Int J Climatol 32(6):953–966
180. Almazroui M (2012) Temperature variability over Saudi Arabia during the period 1978–2010 and its association with global climate indices. J King Abdulaziz Uni: Meteorol Environ Arid Land Agric Sci 23(1). https://doi.org/10.4197/Met.23-1.6

181. Şen Z, Al-Alsheikh A, Al-Turbak A, Al-Bassam A, Al-Dakheel A (2011) Climate change impact and runoff harvesting in arid regions. Arab J Geosci. https://doi.org/10.1007/s12517-011-0354-z
182. Alshehry AS, Belloumi M (2015) Energy consumption, carbon dioxide emissions and economic growth: the case of Saudi Arabia. Renew Sust Energ Rev 41:237–247
183. Alkhathlan K, Javid M (2013) Energy consumption, carbon emissions and economic growth in Saudi Arabia: an aggregate and disaggregate analysis. Energy Policy 62:1525–1532
184. Ouda OKM, Cekirge HM, Raza SAR (2013) An assessment of the potential contribution from waste-to-energy facilities to electricity demand in Saudi Arabia. Energy Convers Manag 75:402–406
185. Nizamia A-S, Rehan M, Ouda OKM, Shahzad K, Sadef Y, Iqbal T, Ismail IMI (2015) An argument for developing waste-to-energy technologies in Saudi Arabia. Chem Eng Trans 45:337–342
186. Ouda OKM, Raza SA, Al-Waked R, Al-Asad JF, Nizami A-S (2015) Waste-to-energy potential in the Western Province of Saudi Arabia. J King Saud Uni Eng Sci. https://doi.org/10.1016/j.jksues.2015.02.002
187. Alsunni AA, Badar A (2011) Energy drinks consumption pattern, perceived benefits and associated adverse effects amongst students of University Of Dammam, Saudi Arabia. J Ayub Med Coll Abbottabad 23(3):3–19
188. Taleb HM, Sharples S (eds) (2011) Developing sustainable residential buildings in Saudi Arabia: a case study. Appl Energy 88(1):383–391
189. Abdel-Aal RE, Al-Garni AZ (1997) Forecasting monthly electric energy consumption in eastern Saudi Arabia using univariate time-series analysis. Energy 22(11):1059–1069
190. Dincer I, Hussain MM, Al-Zaharnah I (2004) Energy and exergy use in public and private sector of Saudi Arabia. Energy Policy 32(14):1615–1624
191. Rehman S, Ahmad A (2004) Assessment of wind energy potential for coastal locations of the Kingdom of Saudi Arabia. Energy 29(8):1105–1115
192. Shaahid SM, El-Amin I (2009) Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia—a way forward for sustainable development. Renew Sust Energ Rev 13(3):625–633
193. Rehman S, Al-Hadhrami LM (2010) Study of a solar PV–diesel–battery hybrid power system for a remotely located population near Rafha, Saudi Arabia. Energy 35(12):4986–4995
194. Neblock T (2006) Saudi Arabia, power, legitimacy and survival. Taylor and Francis Group, UK
195. Rehman S, Halawani TO, Mohandes M (2003) Wind power cost assessment at twenty locations in the kingdom of Saudi Arabia. Renew Energy 28(4):573–583
196. Rahman F, Rehman S, Abdul-Majeed MA (2012) Overview of energy storage systems for storing electricity from renewable energy sources in Saudi Arabia. Renew Sust Energ Rev 16 (1):274–283
197. Elhadidy MA, Shaahid SM (1999) Feasibility of hybrid (wind + solar) power systems for Dhahran, Saudi Arabia. Renew Energy 16(1–4):970–976
198. Al-Gahtani SS, Hubona GS, Wang J (2007) Information technology (IT) in Saudi Arabia: culture and the acceptance and use of IT. Inf Manag 44(8):681–691
199. Alnatheer O (2005) The potential contribution of renewable energy to electricity supply in Saudi Arabia. Energy Policy 33(18):2298–2312
200. Al-Ibrahim AM, Varnham A (2010) A review of inlet air-cooling technologies for enhancing the performance of combustion turbines in Saudi Arabia. Appl Therm Eng 30 (14–15):1879–1888
201. Mansouri NY, Crookes RJ, Korakianitis T (2013) A projection of energy consumption and carbon dioxide emissions in the electricity sector for Saudi Arabia: the case for carbon capture and storage and solar photovoltaics. Energy Policy 63:681–695
202. AlmasoudHatim H, Gandayh M (2015) Future of solar energy in Saudi Arabia. J King Saud Uni Eng Sci 27(2):153–157

203. Al-Saleh Y (2009) Renewable energy scenarios for major oil-producing nations: the case of Saudi Arabia. Futures 41(9):650–662
204. Şahin AZ, Aksakal A (1998) Wind power energy potential at the northeastern region of Saudi Arabia. Renew Energy 14(1–4):435–440
205. Khan MSM, Kaneesamkandi Z (2013) Biodegradable waste to biogas: renewable energy option for the Kingdom of Saudi Arabia. Int J Innov Appl Stud 4(1):101–113
206. Alruqaie IM, Alharbi BH (2012) Environmental advantage assessment of recycling food waste in Riyadh, Saudi Arabia. Res J Environ Sci 6:230–237. [Online] Available: www.ariyriaydh.com/english/2013. Mar 15 2013
207. Benghanem M, Mellit A (2010) Radial Basis Function Network-based prediction of global solar radiation data: application for sizing of a stand-alone photovoltaic system at Al-Madinah, Saudi Arabia. Energy 35(9):3751–3762
208. Rehman S, El-Amin I (2012) Performance evaluation of an off-grid photovoltaic system in Saudi Arabia. Energy 46(1):451–458
209. Shaahid SM, El-Amin I, Rehman S, Al-Shehri A, Ahmad F, Bakashwain J, Al-Hadhrami LM (2010) Techno-economic potential of retrofitting diesel power systems with hybrid wind-photovoltaic-diesel systems for off-grid electrification of remote villages of Saudi Arabia. Int J Green Energy 7(6):632–646
210. Shaahid SM, Al-Hadhrami LM, Rahman MK (2014) Review of economic assessment of hybrid photovoltaic-diesel-battery power systems for residential loads for different provinces of Saudi Arabia. Renew Sust Energ Rev 31:174–181
211. Ramli MAM, Hiendro A, Sedraoui K, Twaha S (2015) Optimal sizing of grid-connected photovoltaic energy system in Saudi Arabia. Renew Energy 75:489–495
212. Li X, Tschumi M, Han H, Babkair SS, Alzubaydi RA, Ansari AA, Habib SS, Nazeeruddin MK, Zakeeruddin SM, Grätzel M (2015) Outdoor performance and stability under elevated temperatures and long-term light soaking of triple-layer mesoporous perovskite photovoltaics. Energ Technol 3(6):551–555
213. Adinoyi MJ, Said SAM (2013) Effect of dust accumulation on the power outputs of solar photovoltaic modules. Renew Energy 60:633–636
214. Benghanem M, Daffallah KO, Joraid AA, Alamri SN, Jaber A (2013) Performances of solar water pumping system using helical pump for a deep well: a case study for Madinah, Saudi Arabia. Energy Convers Manag 65:50–56
215. Mekhilef S, Saidur R, Kamalisarvestani M (2012) Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. Renew Sust Energ Rev 16(5):2920–2925
216. Rehman S, Sahin AZ (2015) Performance comparison of diesel and solar photovoltaic power systems for water pumping in Saudi Arabia. Int J Green Energy 12(7):702–713
217. Zell E, Gasim S, Wilcox S, Katamoura S, Stoffel T, Shibli H, Engel-Cox J, AlSubie M (2015) Assessment of solar radiation resources in Saudi Arabia. Sol Energy 119:422–438
218. El Khashab H, Al Ghamedi M (2015) Comparison between hybrid renewable energy systems in Saudi Arabia. J Electr Syst Inf Technol 2(1):111–119
219. Shoup JA (2007) Culture and costumes of Jordan. Greenwood Press, London
220. Ghane AA (2011) Climatology of the areal precipitation in Amman/Jordan. Int J Climatol 31 (9):1328–1333
221. Hotzl H, Moller P, Rosnthal E (2009) The water of Jordan vally, scarcity and deteroration of groundwater and its impact on the regional development. Springer, Switzerland
222. Allan JA (2001) The Middle East water question: hydropolitics and the global economy. I. B. Tauris, London
223. Samuels R, Rimmer A, Hartmann A (2010) Climate change impacts on Jordan river flow: downscaling application from a regional climate model. J Hydrometeorol 11:860–879
224. Akash B, Mohsen MS (2003) Current situation of energy consumption in the Jordanian industry. Energy Convers Manag 44:1501–1510
225. Tamimi A (1993) Energy situation in Jordan. Energy Convers Manag 34:519–521

226. Al-nugrush A Jordan energy statistics compilation methods, IEA energy statistics and indicators training Cairo 20–23 Oct 2014, Egypt
227. Foster V, Yepes T (2006) Is cost recovery a feasible objective for water and electricity? The Latin American experience, World Bank policy research working paper 3943 Bernstein
228. Bernstein MA, Griffin J (2005) Regional differences in the price-elasticity of demand for energy. RAND corporation technical report, mimeo
229. Filippini M, Pachauri S (2002) Elasticities of electricity demand in urban Indian households. CEPE working paper Nr. 16, Mar 2002
230. Komives K, Halpern J, Foster V, Wodon Q (2006) The distributional incidence of residential water and electricity subsidies. World Bank policy research working paper 3878
231. Taylor LD (1975) The demand for electricity: a survey. Bell J Econ 6(1) (Spring, 1975):74–110
232. Hashemite Kingdom of Jordan, Electricity Subsidies and Household Welfare in Jordan Can households afford to pay for the budget crisis? Background paper for the Jordan Poverty Reduction Strategy, 2011
233. http://www.jordantimes.com/news/local/power-consumption-kingdom-rises-51
234. Mohsen MS, Akash BA (1998) Energy analysis of the steel making industry. Int J Energy Res 22(12):1049–1054
235. JMEMR Report, Survey of energy consumption in the industrial sector. Amman, Jordan: Jordanian Ministry of Energy and Mineral Resources, Oct 1998
236. Akash BA, Mohsen MS (1999) Energy analysis of Jordan_s urban residential sector. Energy 24(9):823–831
237. Annual report for the year 1999, National Electric Power Company, Amman, Jordan, 2000
238. Mohsen MS, Akash BA Evaluation of domestic solar water heating systems in Jordan using analytic hierarchy process. Energy Convers Manag (1997) 38(18):1815–22
239. Garen J, Jepsen C, Saunoris J The relationship between electricity prices and electricity demand, economic growth, and employment, draft report prepared for Kentucky Department for Energy Development and Independence Coal Education Grant RFP Number 127.
240. Momani MA (2013) Factors affecting electricity demand in Jordan. Energy Power Eng 5:50–58
241. Cartalis C, Synodinou A, Proedrou M, Tsangrassoulis A, Santamouris M (2001) Modifications in energy demand in urban areas as a result of climate changes: an assessment for the southeast Mediterranean Region. Energy Convers Manag 42(14):1647–1656
242. Al-Ghandoor A, Samhouri M (2009) Electricity Consumption in the Industrial Sector of Jordan: Application of Multivariate Linear Regression and Adaptive Neuro-Fuzzy Techniques. Jordan J Mech Indust Eng 3(1):69–76
243. Department of Statistics (DoS) Statistical yearbook 2007. Amman, Jordan; 2008
244. DoS Statistical yearbook 1985. Amman, Jordan; 1986
245. DoS Statistical yearbook 2005. Amman, Jordan; 2006
246. Ministry of Energy and Mineral Resources (MEMR). Annual report 2007. Amman, Jordan; 2008.
247. Al-Ghandoor A, Phelan PE, Villalobos R, Phelan BE (2008) Modeling and forecasting the U.S. manufacturing aggregate energy intensity. Int J Energy Res 32:91–106
248. Al-Ghandoor A, Phelan PE, Villalobos R, Phelan BE (2008) U.S. manufacturing aggregate energy intensity decomposition: the application of multivariate regression analysis. Int J Energy Res 32:501–513
249. Al-Ghandoor A, Al-Hinti I, Jaber JO, Sawalha SA (2008) Electricity consumption and associated GHG emissions of the Jordanian industrial sector: empirical analysis and future projections. Energy Policy 36:258–267
250. Jaber JO, Jaber QM, Sawallha SA, Mohsen MS (2008) Evaluation of conventional and renewable energy sources for space heating in the household sector. Renew Sust Energ Rev 12:278–289

251. Jaber JO, Mohsen MS, Al-Sarkhi A, Akash B Energy analysis of Jordan's commercial sector. Energy Policy 31:887–894
252. Jaber JO, Mohsen MS, Probert S, Alees M (2001) Future electricity-demands and greenhouse-gas emissions in Jordan. Appl Energy 69:1–18
253. Jaber JO (2002) Future energy consumption and greenhouse gas emissions in Jordanian industries. Appl Energy 71:15–30
254. http://www.jo.undp.org/content/dam/jordan/docs/Env/EE_Impact%20of%20the%20Upcoming%20EE%20Standards%20in%20Jordan.pdf
255. Gamba A New energy sources for Jordan: macroeconomic impact and policy considerations, IMF working paper, International Monetary Fund 2015.
256. Ministry of Energy and Mineral Resources Kingdom of Jordan, (National Energy Efficiency Action Plan), 2013
257. Tawalbeh M Energy efficiency; current trends and future perspectives in Jordan. International workshop cooperation between EU and Mediterranean partner countries in energy sector, 2016

Chapter 7
Adopted Iraqi Photovoltaic Projects

7.1 Introduction

God has given Iraq many gifts. These gifts have contributed to the development of Iraqi society over its long history by changing its lifestyles and transforming it from a primitive area to an urban and suburban area. The great impact of the formation of communities and cities on the banks of the Tigris and Euphrates for thousands of years and the exploitation of fertile land in agriculture and grazing, so-called the land of Iraq "the land of blackness" because of the large areas of cultivated land and the spread of green areas throughout [1].

After the industrial revolution and the need for searching for sources of energy for industrial progress, Iraq's abundant oil had the most significant effect in its development. This country reached the ranks of the developed countries with Iraq relying on its own abilities to explore, extract, and export oil. However, Iraq has entered into a series of consecutive problems, which have not yet been realized, leading to loss of rank and status [2].

Oil as a nonrenewable energy must one day be depleted, so Iraq must rely on alternative sources, renewable and clean, to meet the country's need for energy. Iraq today needs 30,000 megawatts (MW) of electricity; the thermal, gas, and hydroelectric production plants supply Iraq with about 17 thousand MW at best. To meet this the shortage in electricity, the Ministry of Electricity has resorted to importing electricity from neighboring countries at a rate of 1,700 MW to address the difference between the country's actual need for electricity and production capacity [3]. However, the electricity conditions in Iraq have not resolved changed this difference. The great demand for electricity is still urgent and necessary. In the summer temperatures exceed 50 °C, which has led to the private sector being called on to adopt diesel generators to generate electricity. These generators have become widespread in every neighborhood and alley, with wires extended and leading from and to everywhere, in a scene that can best be described as "non-civilized" [4].

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There are more than 150,000 generators in the capital Baghdad alone. The average consumption of one generator of diesel is 120 L per day. A simple calculation shows that a total of 18 million L of diesel is burned daily in Baghdad alone to generate electricity by diesel generators [5]. In addition to the noise caused by these generators, they create clouds of black smoke, an important cause of global warming and climate change. Thus, this provides a picture not befitting Baghdad's beauty, without even considering the volume of fuel being used in the 18 other Iraqi provinces [6].

It has become urgent and necessary to find energy alternatives, and one such alternative presents itself in the desert of western Iraq. Specifically, the investment is to generate electricity from the solar energy that is abundant throughout the year. Findings of a historical Western study that are circulated by the Iraqi trustees state: If Iraq takes advantage of an area in the western desert (as much as the area of Kuwait) for solar energy projects, this country will be able to generate electricity to meet the needs of half a billion people. So, what if more areas of the western Sahara were exploited?

The western region of Iraq is not only abundant in solar energy, it also contains the raw materials used in the manufacture of solar panels, silica sand. International companies can set up manufacturing plants for solar panels, taking advantage of the raw materials used in those industries, providing job opportunities for Iraqi youth, thus reducing the current high unemployment rates [7].

It is not fair to say that solar energy projects are expensive. Over the past 14 years, Iraq has spent more than $45 billion on the electricity sector. Iraqi citizens have spent in the same sector over the past 14 years more than $80 billion. The value of the money spent during that period can improve the reality of electricity enough to buy General Electric's assets with all its branches, and use it to produce lines and cover the cost of transporting them to Iraq to start setting up new power plants in each Iraqi city [8].

The price of solar cells is ever decreasing and the area occupied by the panels are also constantly decreasing as a result of the technological progress in the solar panel industry. The amount of solar power the average Iraqi citizen who will need to install solar cells on the roof of his home in any Iraqi city, where the sun shines more than 10 h a day, to operate a television, computer, refrigerator, and water cooler in addition to the electric light bulbs, will not exceed the solar energy capacity of 1.5 kilowatts [9]. The generation of this amount of electricity requires up to $2500 (to set up six solar panels each of 260 watts and converters and wires to connect with the house) in the USA. Prices have begun to fall sharply with the technological development that has been achieved in the production and improvement of the quality of solar panels [10].

There is a difference in the generation of power panels ranging from 10 watts that are used to charge small batteries and mobiles. The larger the photovoltaic (PV) panel the more effective the electricity that is generated, up to 200 watts. In residential homes, the PV panels cost up to $200 per plate with a length of 1.5 m and width of about 80 cm and weight of about 14 kg. Another problem that hinders the advancement of this type of alternative energy is the low availability of batteries in today's world to store and provide energy to the consumer quickly and cheaply, in addition to their cost, which are still "imaginary" compared to lithium batteries [11]. The German company Solarpateri has produced a small battery that can be hung on the wall of the basement and can save the solar energy produced by the solar panels on the roof of the house, and will be available to the homeowner at a price lower than the traditional grid [12].

This battery can be considered a revolution in the world of alternative energy, starting with the crucial second phase of a solar lifecycle. This battery saves not only a lot of money for the consumer, but also contributes to the preservation of the environment. It can also launch an era of electrical "individuality" where each household produces the amount of energy it needs without the need for large networks. With such a battery, the consumer may be able to produce enough energy to sell the excess to the neighbors' house or perhaps to a nearby store [13].

The Iraqi government should raise the awareness of citizens in this area through technical support by preventing the production and use of electric water heaters in houses and laboratories, and providing compensation for solar systems. The government should also encourage and facilitate the establishment of solar cells and establish companies that produce solar cells, as well as encourage the use of solar energy as clean energy. Iraq is a prime candidate for such projects [14].

Clean energy represents an important focus of most countries. The adoption of solar energy in the production of electricity needs mechanisms and plans prepared by experts specialized in this regard. Some experiments carried out on a small scale in some cities and towns of Iraq have achieved acceptable results, and it is important to develop them in a deliberate manner and expand horizontally according to their economic feasibility. The move towards clean energy requires communication with specialized international companies that can accomplish such projects that are in line with global trends. This step allows the country to communicate with the developed world, which has adopted this type of advanced service [15].

The employment of successful experiences of neighboring countries can help to overcome many of the challenges facing the adoption of clean energy in Iraq. The Iraqi government should form committees of different competent bodies working to develop the adoption of this technology. This experience can be successful when quality solar panels that reduce costs and effort are adopted [16].

With regard to the issue of clean energy (solar), the interests of many Iraqi citizens were not met after the failure of many experiments to achieve good results. Projects such as the lighting of roads adopted in some cities of Iraq went out of service after a short period of operation, creating a culture of mistrust and causing these projects to lose the opportunity to achieve their goals. The success of these projects depends on the success of selecting specialized companies that supply the equipment used in these types of services. This is especially important since many countries in the world are beginning to rely on clean energy to provide many services to their populations [17].

The experience of lighting some streets in Baghdad and other Iraqi cities with solar cells was a big failure, which adversely affected the confidence of citizens in this technique. The Iraqi government wasted $17,780,000 as a result of the failure of the Baghdad solar street lighting project. The electricity distribution departments on both sides of “Karkh” and “Rusafa” carried out a project to install solar lighting in the streets starting in late 2008 and continuing through 2009 and 2010. They then raised some of these systems of solar panels, based on a charging system, and integrated lighting fixtures from 2011 to 2016. The failure of the lighting the streets project of the capital by solar energy led to the waste of the purchased solar units and the entire amount spent on the operation of the project, maintenance, and upgrading [18].

The absence of plans and programs in advance of the installation of these structures in the areas of Baghdad was the reason why many of these projects did not succeed in using solar cells raised and stored in the warehouses of the directorates of the ministry. It requires the Ministry to take quick and appropriate action toward the rehabilitation of these cells and the preparation of engineering designs for use in small projects to produce electricity. When conducting several contracts with foreign and Iraqi companies for the purpose of buying units of lighting, including solar cells and transformers and batteries, the Ministry of Electricity did not conduct a study into the technical and economic feasibility of the process of lighting the streets of Baghdad and the provinces depending on solar energy by specialists in the ministry and the directorates affiliated to them [19].

7.2 Modern Projects

The interest in the use of solar cells to produce electricity has increased after many studies have shown high rates of environmental pollution resulting from generating electricity with local generators. Although the beginnings were faltering and slow, the future is promising due to the availability of all the requirements for the successful use of solar cells from capital, environmental, and human potential.

Al Mansour General Company has a newly integrated laboratory for the production and testing of solar panels of all kinds imported from an Italian company specialized in the field of energy. The production capacity of this plant is 3 MW/year. The company also signed a contract with the Industrial Research and Development Authority (one of the Ministry of Industry’s formations) for the purpose of processing 565 solar panels with a capacity of 250 W each. This contract has been completed, and many contracts with the ministries and state institutions have been conducted successfully [20].

The General Enterprise for Groundwater has previously endeavored to utilize solar energy in the provision of water. This experiment has achieved great success in operating the irrigation systems from wells to serve the citizens and select the latest and most suitable systems to keep pace with the continuous development in this field [21]. This energy has helped ease demands on electricity and reduced the high costs of fuel, lubricating oils, and maintenance. Therefore, the Enterprise has developed professional competencies through training pumping crews in several training centers for the development of solar systems to be distributed to most of Iraq’s governorates. The success rate of this experiment has been estimated at 90% or more. The advantages of using this energy include very little damage since the solar panels are guaranteed for 25 years while other systems are guaranteed for not less than 5 years. Unlike other technologies, this technology has contributed to the maintenance of our economy and reduces the noise and pollution of the environment that was caused by generators, in addition to the rationalization in electricity consumption [22].

The exploitation of solar energy in pumping systems for wells is a big and highly technical step carried out by the General Enterprise of groundwater in Iraq. Having contributed to the advancement and development in various areas, the exploitation of solar energy and harnessing of the operation of these systems helps to obtain abundant water and maintain a clean environment free from pollution. For greater success of this experiment, the Enterprise has used these solar-powered systems in a number of wells that have been completed in the alternative water project “Al-Saqi” in the holy province of Karbala [23]. This project aims to avoid the interruption of or decrease in water levels in the Euphrates River and to provide the basic water needs in emergency situations that the province may be exposed to. The plan is to equip these wells with 20 solar pumping crews. During the course of this project, 11 solar pumping crews were installed and 19 pumping crews were equipped. The projects of the General Enterprise for Groundwater blocked the immediate needs in this area and provided large amounts of water to cover the daily needs of citizens in villages and areas suffering from water scarcity, as well as providing irrigation for animals and agricultural land [24].

Al-Ezz General Company, one of the Ministry of Industry and Minerals companies, has manufactured a solar system for domestic use. The company manufactured a solar energy system to provide an electrical capacity of 1 kW and was able to manufacture another system with a capacity of 2.2 kW. The system will provide electricity for 10 h a day and 6 h a night. It consists of solar cell panels that are guaranteed for 20 years and are claimed to not be affected by climatic conditions in Iraq. The company itself has equipped many areas in Baghdad with solar lighting poles [25].

Iraq, the World Technology Company, and the Ministry of Municipalities and Public Works carried out the largest solar project in the Middle East with the deployment of 729 integrated solar plants for the purification and desalination of wells, ponds, rivers, and drinking water supplies. They were distributed to 700 villages to cover the needs of more than 1.5 million citizens. The project was implemented in two stages: Phase I - construction of 379 stations during the period 2009–2010; Phase II, the construction of 350 stations for the period 2010–2011. The project reduced production costs by up to 70%. In addition, it provided potable water for villagers and rural areas [26].

The Iraqi Ministry of Electricity concluded the first two contracts to install and operate four photoelectric stations working on solar energy by investing 230 MW in the provinces of Al-Muthanna and Najaf Governorate. The four photovoltaic stations will be distributed in Al-Muthanna Governorate (Sawa, one station with a capacity of 30 MW, two stations with a production capacity of 50 MW, and Al-Khuder with a capacity of 50 MW); the total capacity in Muthanna Governorate is 130 MW. The fourth station has a production capacity of 100 MW in the Al-Haidariyah area in Al-Najaf Governorate. Such contracts represent a new direction for the ministry in the investment of sunlight to generate electricity. The investment of this gift is positive in increasing the productive capacity of the national electrical system, which is reflected in the increase in hours of processing for citizens [27].

The General Company for Electrical and Electronic Industries, one of the companies of the Ministry of Industry and Minerals, set up a solar water filtration and sterilization system in a school in the city of Samawah. The company is seeking to use renewable energy in the field of treatment, sterilization, and filtering of water by wells where there was a successful experiment to install a system at a break station for visitors in Karbala and was intended to provide water. The use of such systems reduces the amount of environmental pollution and noise, is considered environmentally friendly, and is used in remote areas away from the city where there is no electricity [28].

The Iraqi Ministry of Science and Technology is studying the project of installing solar panels on citizens' houses to reduce the cost of electrical energy and activate the mutual sale between these panels and the national network. The project of installing solar panels on the roofs of citizens' homes in order to reduce the pressure on electricity and not rely on the national network mainly aims to create mutual benefit between the citizens and the Ministry of Electricity. As the link of those panels will contribute to reducing the pressure on energy, citizens can sell the ministry any quantity that exceeds their own need. The most striking feature of the project is that the panels are cheap worldwide and will not significantly affect the state budget as they claimed. This does not mean that this project does not need money, however, especially as it is a new project for the first time in the country, but it will provide great benefit for several years under the system of sustainability of energy [29].

Iraq has abundant sun, but does not invest that energy. This project will open new horizons for the country, including the investment of solar energy as heat energy for the purposes of steam, heaters, and other purposes. Iraq is one of the 110 member states in one of the organizations in Abu Dhabi concerned with environmentally friendly energies [30].

Al-Zawra General Company, one of the Ministry of Industry and Minerals companies, announced the manufacture of solar energy systems in cooperation with the Ministry of Electricity. The Ministry of electricity will be the beneficiary of this project by exploiting the disabled solar cells located on the pillars of lighting rehabilitation and operation. This project is based on the dependence and utilization of the idle solar cells currently located on the poles of street lighting where these cells are collected for recycling into multi-capacity electric systems. The 15 kW system is installed in state institutions and circuits and is synchronized with the national grid. In turn, it receives the extra electrical energy produced by this system, thus forming a source of support and utility for national electricity in Iraq. The adoption of a hybrid home system with a capacity of 5 kW will generate electricity for homes, charge batteries, and then return to the national network excess electricity, thus contributing to the reduced cost of electricity that currently sits on the shoulders of the citizen.

The Ministry of Electricity has contracted with a commercial bank that adopts the subject of financing and the purchase of systems to be sold to citizens in the form of installments as a plan to market this product. A specialized team will be established and trained to maintain these systems. The company also received an invitation from the Ministry of Electricity to set up a solar power station with a capacity of 1 MW to provide 50% of the electricity needed by the headquarters of the ministry. There is also a move by the Ministry of Industry and Minerals to the General Zora Company to set up a power station similar to the project of the Ministry of Electricity to meet the electricity needs of the headquarters of the Ministry of Industry, and this will determine the capacity of the station according to the available space for the installation of solar cells.

Iraq has suffered a shortage of electricity since the beginning of 1990, but in the past 3 years it has seen an improvement in the provision of electric power after the opening of a number of electric stations. These stations include Zubaidiyah in Wasit, Al-Khayrat in Karbala, Haidariyah in Najaf, and the gas station in Maysan, in addition to the two stations in Diwaniya and Sadr station in Baghdad. The Shatt al-Arab and Rumaila stations in Basra and the gas station in Kirkuk entered to surface [31]. The electricity operating and supplying hours continued to be about 20 h, especially in low temperatures. Working hours are significantly reduced with higher temperatures and increasing loads on the power plants during peak times. Therefore, the Ministry of Electricity has initiated the design and construction of a 5 kW domestic solar system, which will contribute to solving the problem of remote villages and districts, and may be introduced in the residential sector to reduce peak loads. This system works with the conditions of the Iraqi network and in three operational modes at the same time (with the national network, without the national network, and without national electricity). The system will export the surplus of its daily production to the national network. This system can solve the problem of remote villages and districts isolated from the national network [32].

The Iraqi Ministry of Electricity announced on 19 October, 2016 a plan to invest in solar energy and encourage its use to meet the shortfall suffered by Iraq in this area. It will start with Muthanna province, because the region is suitable for this specialization. The Muthanna Desert is characterized by its vast area, very high temperatures, and intense brightness, in addition to the existence of corridors of wind. The industrial boom witnessed by the province provides the need for clean energy in quantities of suitable production up to 400 MW until 2020 [33].

The Ministry of Electricity has called on the investment companies to set up a 50 MW solar PV plant in Salman district as part of this campaign. The Ministry of Electricity has announced that it has identified 12 sites for the construction of investment solar systems, which is expected to contribute about 1,500 MW to the national system by 2020.

The government and popular tendencies towards the use of solar cells is still new and in its infancy. The Iraqi government must support this trend aggressively in order to improve air quality, increase electricity production capacity, and reduce dependence on fossil fuels. The move toward photovoltaic cell stations is the first step to help solve the real energy problem in Iraq and the beginning of self-sufficiency in energy. The use of clean and available solar energy represents one of the methods of self-reliance and reduces the need for traditional energy methods.

7.3 Conclusions

Iraq's major achievements and recommendations on renewable energy development can be summarized as follows:

- Government support is needed for implementation of small renewable energy pilot projects, especially those that serve people in rural areas.
- Financial support for studies that lead to the investigation of renewable energy in Iraq and their applications is needed.
- Introduce solar thermal collectors in public buildings to produce hot tap water can be considered as an introduction to reducing dependence on fossil fuel resources.
- Introduce of solar photovoltaic and water pumping systems for irrigation applications for the public.
- Increase people's awareness towards using renewable energy and, particularly, photovoltaic systems.
- Encourage and sponsor fourth-year projects in renewable energy. In addition, support and encourage research programs as well as M.Sc. and Ph.D. programs in renewable energy science that will serve in the workforce and as catalysts in promoting increased use of renewable energies in Iraq.
- Encourage the gradual move toward a more conscious and sustainable use of energy resources.

References

1. Yaseen BR, Al Asaady KA, Kazem AA, Chaichan MT (2016) Environmental impacts of salt tide in Shatt al-Arab-Basra/Iraq. IOSR J Environ Sci Toxicol Food Technol 10(1–2):35–43
2. Alwaely AA, Al-qaralocy HN, Al-Asadi KA, Chaichan MT, Kazem HA (2015) The environmental aftermath resulted from chemical bombardment of Halabja Territory for the period 1988–2014. Int J Scientific Eng Res 6(9):40–44
3. Chaichan MT, Kazem HA (2012) Status and future prospects of renewable energy in Iraq. Renew Sust Energ Rev 16(1):6007–6012
4. Al-Waeely AA, Salman SD, Abdol-Reza WK, Chaichan MT, Kazem HA, Al-Jibori HSS (2014) Evaluation of the spatial distribution of shared electrical generators and their environmental effects at Al-Sader City-Baghdad-Iraq. Int J Eng Technol IJET-IJENS 14(2):16–23
5. Ismail MS, Moghavvemi M, Mahli TMI (2013) Techno-economic analysis of an optimized photovoltaic and diesel generator hybrid power system for remote houses in a tropical climate. Energy Convers Manag 69:163–173

6. Mohammed A, Pasupuleti J, Khatib T, Elmenreich W (2015) A review of process and operational system control of hybrid photovoltaic/diesel generator systems. Renew Sust Energ Rev 44:436–446
7. Freestone IC (2006) Glass production in Late Antiquity and the Early Islamic period: a geochemical perspective. Geol Soc Lond Spec Publ 257:201–216
8. Al-Karaghouli A, Kazmerski LL (2010) Optimization and life-cycle cost of health clinic PV system for a rural area in Southern Iraq using HOMER software. Sol Energy 84(4):710–714
9. Jakobsen PV (2000) Focus on the CNN effect misses the point: the real media impact on conflict management is invisible and indirect. J Peace Res 37(2):131–143
10. Doyle P, Ja K, Iraq has an opportunity to become a solar leader, Winter 2009–2010
11. Rashid S (2012) Electricity problem in Iraq, Economics and Planning of Technical Urban Infrastructure Systems
12. Abdulrahman AA (2014) Grid-Connected Photo Voltaic System Design for Koya Software Engineering Department in Iraq. Int J Eng Trends Technol (IJETT) 10(2):81–84
13. Jacobs W, Hall PV (2007) What conditions supply chain strategies of ports? The case of Dubai. GeoJournal 68(4):327–342
14. Al-Douri Y, Abed FM (2016) Solar energy status in Iraq: abundant or not—steps forward. J Renew Sustain Energy 8:025905
15. Luai SR, Al-Hadhrami M (2010) Study of a solar PV–diesel–battery hybrid power system for a remotely located population near Rafha, Saudi Arabia. Energy 35(12):4986–4995
16. Ali MME, Salih SK (2013) A visual basic-based tool for design of stand-alone solar power systems. Energy Procedia 36:1255–1264
17. Al-Shamani AN, Othman MYH, Mat S, Ruslan MH, Abed AM, Sopian K (2015) Design & Sizing of Stand-alone Solar Power Systems A house Iraq. Recent Adv Renewable Energy Sources I:145–150
18. Azooz AA, Abid WU, Ibrahim SA (2013) Gravitational solar energy storage case study: Mosul Dam. J Asian Scientific Res 3(4):373–380
19. Ahmed SA, Mahammed HO (2012) A statistical analysis of wind power density based on the Weibull and Ralyeigh models of "Penjwen region" Sulaimani/Iraq, Jordan. J Mech Indust Eng 6 (2):135–140
20. Al-Jawhar HD (2016) Management of the cost overrun of Baghdad University projects using Earned Value Management (EVM) and Value Engineering (VE), ZANCO. J Pure Appl Sci 28 (2):240–250
21. UNDP (United Nations Development Programme) (2014) Catalysing the use of Solar Photovoltaic Energy, Project ID: 00089774
22. Al-Khatteeb L, Istepanian H (2015) Turn a light on: electricity sector reform in Iraq. Brookings Institution, USA
23. Parsons Brinckerhoff (2010) Republic of Iraq, Ministry of Electricity, Iraq and KRG Electricity Master Plans, Final Report, Executive Summary. vol 1
24. Istepanian H (2014) Iraq's electricity crisis. Electr J 27(4):51–69
25. Istepanian H, Al-Khatteeb L, Electricity consumption and economic growth in Iraq, presentation, Power-Gen Middle East Conference, Abu Dhabi, October 2014
26. Sachs J, Asad S, Qaragholi H (2011) Iraq's power crisis and the need to re-engage the private sector—smartly, Middle East Economic Survey, 6 February 2011
27. Al-Khatteeb L, Istepanian H (2014) Iraq Draft Electricity Law: What's Right, What's Wrong, Petroleum Economist
28. Hafidh H (2014) Iraq signs deal to import Iranian gas. Wall Street J. http://online.wsj.com/news/articles/SB10001424127887324783204578621353730256208
29. Iraqi Ministry of Oil. Monthly Reports. Accessed 22 Feb 2015. http://www.oil.gov.iq/index.php?name=sthlak>; IEA, Iraq Energy Outlook, 72
30. Government of Iraq. The Integrated National Energy Strategy for Iraq, 2010–2030, June 2013
31. IRENA (International Renewable Energy Agency), Rethinking Energy (2017)

32. Davies M et al (2015) Developing renewable energy projects a guide to achieving success in the Middle East, second edition, Eversheds
33. Yang P (2014) Green energy intensity: development of renewable energy generation and consumption in major economies. J Econ Develop Studies 2(1):31–49

Chapter 8
Iraq's Future Strategies in the Use of PV Plants

8.1 Introduction

The task of preserving the Iraqi environment, improving its properties, solving its problems, and harmonizing with its national, regional, and international requirements is one of the most important challenges facing Iraq. The environment in Iraq suffers from many problems caused by natural and human factors as well as the wrong policies of previous governments, which resulted in several wars and international sanctions and unfair and abhorrent economic blockade. All these factors have affected the environment, and the restoration of the former environment needs to combine the efforts of the citizens and the government with the development of sophisticated and deliberate strategies [1].

Achieving clear development in the field of energy is done by identifying national energy policies, including but not limited to climate protection by reducing greenhouse gas emissions, developing and diversifying national energy sources, protecting the health of citizens by reducing pollutants emitted into the air, and avoiding high-risk technologies such as nuclear power. The use of renewable energies can be considered appropriate for many, if not all, of these objectives.

Air pollution is an important issue as Iraq lacks data on this aspect. Pollution is calculated using estimated data obtained through the amount of fuel used in furneces and boilers, and from the amount of exhuast gases emitted from burners. The burning of fossil fuels in these sources results in air pollutants such as particulate matter, lead, carbon dioxide, sulfur dioxide and ash. Environmental pollution is linked to the rate of economic growth and the increase in primary energy consumption. Therefore, the talk about pollution and how to limit it is in the field of economics. The talk about reducing pollution necessarily means slowing economic growth, especially in the short term. It is known that this is contrary to the economic objectives of most societies aimed at continued growth [2].

The increasing demand for energy at the present time and in the future prompted the countries of the world to research the use of all available alternatives from energy

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sources. The research, development, and application of renewable energies have become a priority in terms of clean, available, and free sources, which are promising and appropriate alternatives to meet the growing demand for electricity [3].

Iraq has abundant sources of renewable energy, especially solar energy, as this country is located adjacent to the solar belt area, in addition to the potential to take advantage of its water resources. The optimal solution to compensate for the acute shortage of power supply is to exploit available renewable sources of energy. The Iraqi government has adopted the transfer of technologies for the exploitation of solar cells to generate electricity and equipment manufacturing as a strategic option to ensure the lack of electricity supply and diversification of energy sources of the country. Reducing the consumption of fossil fuels, as Iraq is one of the most important producers globally, means keeping fossil resources as strategic stocks for future generations. The encouraging geographical position for Iraq calls for benefiting from this energy and the use of other resources such as oil and gas to finance and develop PV projects, especially in remote locations, which require high costs of electricity power [4, 5].

Iraq's power generation systems rely on traditional power generation units that cover day-to-day loads, taking into account the nature of peak times and the availability of adequate rotary reserves. Iraq's richness in oil and natural gas supports this. However, oil prices have seen a series of collapses in recent times and are still deteriorating. This fluctuation caused oil prices to be reflected in the income of many countries with a rent economy, including Iraq, which depends on oil revenues mainly in the establishment and sustainability of development. In Iraq, the risks of this collapse are reflected in the erosion of foreign currency reserves. It is expected that this will lead to the disruption of many development programs in light of the urgent need for the continuity of such plans to prevent further deterioration of aspects of economic and social development [6].

In light of the instability in the oil markets between 2008 and today, the search for other nontraditional sources of energy, especially renewable sources, can be relied upon to contribute to meet the increasing demand. Diversifying energy sources, improving production efficiency, and reducing demand are critical for Iraq. Statistical estimates indicate an increase in electricity demand with an average annual growth rate of about 8% [7].

The development of the Iraqi electricity sector is of central importance in the future of Iraq. The biggest challenge is to provide an adequate supply of electricity to citizens and to eliminate the large generation deficit in relation to the demand resulting from the harsh conditions experienced by the country over the past 30 years. Meeting the increase in demand due to economic and population growth depends on the development of the electricity system in Iraq in a way that supports economic and social development to the fullest, especially by making sound choices regarding the technologies and fuels used to generate electricity and through improving the network infrastructure and reforming the electricity system from generation, transportation, and distribution [8].

Thermal power stations account for 93.5% of generated energy, while the remaining 6.5% of energy sources are 6.2% hydraulic energy and 0.3% wind and solar energy. Steam and cycle units based on diesel and natural gas are most commonly used to produce electricity [9].

Government participation varies with the diverse organizational structures of the energy sectors. While independent government bodies deal with renewable energy issues in several Arab countries such as the Kingdom of Saudi Arabia, the United Arab Emirates, and those around the Mediterranean Sea, the past few years have witnessed a marked boom in the establishment of institutions and legislation that regulates work in renewable energy. We find the inventory of renewable energy activities in the sub-departments within the Ministry of Electricity in Iraq, and so far, there is still a clear lack of legislation governing the work in the field of renewable energy. Despite the magnitude of the renewable energies, such as Iraq's solar energy, its contribution to the energy balance does not reflect the reality of the available resources that can be utilized [10].

The Iraqi Ministry of Electricity has set a plan for the years 2012–2015 aiming to reach a participation rate of up to 2% of renewable energy by the end of 2015. The ministry also aims to activate efficient and rationalization programs by introducing solar heaters and efficient LED lighting equipment, as well as using self-generating systems in the energy distribution sector. It is worth mentioning that Iraq is one of the pioneer countries of the Middle East in the adoption of solar pilot projects by introducing 20,000 solar street lighting systems. The Ministry of Industry has developed a solar panel assembly plant in 2010, in addition to the adoption by several ministries of the state of some pilot projects that focus on the use of solar energy systems in the field of watering, irrigation, and water purification. The strategy of the Ministry of Electricity is based on the contribution of solar cells in the total electricity produced by 10% by the end of 2020 [11].

8.2 Strategic and Institutional Determinants

As for the components of solar water heating systems, many Arab countries have been able to localize their industries due to the simplicity of their technologies compared to other systems such as solar cells and wind power, which helped the growth of the use of these systems in some Arab countries, such as Jordan, Tunisia, and Lebanon, in spite of after-sales service difficulties.

Today, Iraqi solar water heaters, energy-saving lighting systems, solar thermal power, and photovoltaic solar systems are available in local markets, although it suffers from marketing obstacles. These systems lack long-term marketing plans associated with the deployment of renewable power outlets for domestic, commercial, or industrial applications. These systems suffer from high prices of renewable energy systems, resulting in the competitiveness of these systems with their conventional counterparts based on traditional energy. The lack of national marketing plans for these systems is included in the financing facilitation of those wishing to install these systems. This is reflected in the delayed integration of renewable energy applications into the Iraqi market. Such concessional financing can be provided through national banks or regional banks characterized by low interest rates and long repayment periods [12, 13].

The most important determinants that hinder the spread of solar energy in Iraq [14, 15] are the following:

1. Limited policies that attract the private investments and lack of government resources allocated to them
2. Weak policies aimed at creating partnerships in the use of renewable energy sources
3. Limited institutional capacity to develop renewable energy systems and the difficulty of coordinating them
4. Low public awareness of available resources and renewable energy systems that can be used technically and economically
5. The difficulty of implementing a government funding system for renewable energy
6. Limited regional cooperation and coordination in financing renewable energy projects and relying on foreign financing programs

In addition, more importantly, from the point of view of securing energy sources, the role of renewable energy in diversifying energy sources is great, especially for electricity production, thermal heating, and energy security. Solar energy can be considered the best way to enhance energy and oil security for the comming Irqi generations.

Many European countries have enacted laws that encourage investors to engage in electricity production as renewable energy. As for Iraq, the electricity sector relies on the state to own, operate, and manage power stations. The priority of the Iraqi government is to provide this service to citizens in any form regardless of the technologies and the role of the private sector.

The high cost of constructing solar power plants compared to fossil fuel stations and the absence of laws and regulations governing the entry of investors, especially those related to the tariffs and prices of clean electricity produced, as well as other factors related to the large wealth of Iraq and the sources of oil and natural gas, which can be used as fuel to produce electricity at prices much lower than Renewable energy plants, and all these reasons have led to maximizing the role of fossil sources compared to renewable sources of energy.

8.3 Awareness Rising

The Iraqi government has not yet implemented awareness campaigns and programs aimed at users in the domestic, industrial, and governmental sectors as one of the most-used sectors of electricity. Such programs aimed at introducing the importance of the use of alternative sources of electrical energy should be supported by the efforts of the governmental organizations and NGOs or nongovernmental organizations. These organizations can serve to create and organize workshops with public awareness bodies in cities and villages, and awareness campaigns in schools, rural areas and remote communities. Awareness campaigns may include the development of pilot models such as solar water heaters in some service areas (youth pilot centers, health units, etc.). By fermenting such projects in rural areas and training women to use these systems, the general acceptance of these techniques will be faster and smoother. In spite of all the Iraqi universities and research centers in the field of awareness, there is more that can and should be done to change the culture of Iraqi citizens in terms of the importance of the inclusion of renewable energy sources in the daily use associated with normal human activity [16].

8.4 Tariff

One of the most important shortcomings of the Iraqi authorities is the non-application of an electricity tariff related to the time of use. This makes the shift to the use of electrical energy sources from other sources for small units in the residential and commercial sectors very limited, leading to the lack of awareness of the user on the importance of these systems and their economic and environmental feasibility. There is a need to develop mandatory laws for electric tariffs and incentives to promote the use of renewable energy systems and the sale of electricity on the basis of the benefit of companies operating in this field [17].

There are three problems to getting going with renewable in Iraq however:

1. The price of electricity is highly subsidized in Iraq and is sold well below the actual cost of generation. The price of power is hence a very politically sensitive issue.
2. The actual cost of the current generation is already low, because it is based on government subsidized oil and gas prices. Government subsidies to electricity tariffs have made the government's payment for oil and gas supplies very large. If this subsidy is reduced or canceled, the fuel can be sold at a much higher price that improves the state treasury. In Europe and the USA, market gas prices lately have been $8, although right now the US price is over $13/MCF (the highest it is ever been).
3. In theory there could be a partial subsidy for renewable energy through carbon trading, but the Omani government has not set up the required internationally recognized authorities to allow trading in carbon offsets under the Kyoto Protocol (currently worth at least $20 per ton of CO2 saved). At that price, this could then be used to lower the effective "gas price equivalent" by more than $1.20 per MCF.

8.5 Studies, Scientific Research, and Development

There are several research and development centers in the field of renewable energy and energy efficiency. However, the percentage of these centers' participation in the development of future plans and strategies is still limited. These centers have adopted scientific research on a standard basis that takes into consideration the development of means of monitoring, analysis, and measurement. The aim to make a serious contribution to improving the performance of renewable energy systems and raising their role and share of electricity is generated [18].

There are clearly a number of research and development centers in renewable energy and energy efficiency in Iraq. However, the number of these centers is still small, particularly in the field of energy efficiency, and is usually not specialized, and does not have a clear impact in the development of future plans and strategies. To date, there are no plans and research projects in the field of renewable energy and energy efficiency that reflect the importance of the subject and the possibility of contributing to the coverage of energy demand now and in the future. The centers have not produced research and development plans and projects that focus on renewable energy and energy efficiency [15].

The Hashemite Kingdom of Jordan and the Republic of Tunisia focus their research and development plans on solar thermal, photovoltaic, water, wind, biogas and photovoltaic. The Syrian Arab Republic and the Arab Republic of Egypt focus on research and development projects and pilot projects on the energy of photovoltaic and solar thermal systems in the services sector with the addition of biomass research projects. For the State of Palestine, there are limited projects on thermal power. The Iraqi research has included all these options from all practical and scientific aspects, but unfortunately without being taken by decision-makers [19].

Renewable energy has become a focus of most universities and educational institutes in Iraq. Many of them also offer a master's and doctoral degree in renewable energy and energy efficiency. The Nahrain Research Center for Renewable Nanomaterials was inaugurated at Al-Nahrain University, Baghdad. The University of Anbar has also opened a center for renewable energy research. The University of Technology in Baghdad preceded them by establishing the Energy and Renewable Energies Technology Center. These research centers aim to provide many future goals such as [20, 21]:

1. Uniting the efforts of ministries, companies, and research centers of common interest in energy projects and renewable energies. The university and its researchers shall be participants and supervisors of all researches and projects of the State in the field of renewable energies.
2. The introduction of sources of renewable energies and projects within the State's future plan to produce energy and rationalize consumption.
3. Proposing and adopting different forms of support for renewable energy products and subsidizing prices to encourage their use and dissemination of their culture.
4. Establishing assessment, classification, and testing centers whose equipments are sufficient to provide global reliability.

5. Establishing information, training, and development programs for specialized technical personnel.

8.6 Expected Results and Summary

The best solar radiation in the Middle East is in the far south - in Saudi Arabia and Yemen, however, Iraq has very good solar resources. The average solar radiation in Iraq is similar to that in North Africa. Iraq also has some history of research on solar energy, which has been greatly reduced in decades of wars and sanctions, and the Ministries of Electricity and Science and Technology are sponsoring solar research activities. The Ministry of Electricity has a number of research solar stations operating outside the network. Despite the strong financial resources of the Ministry, the generation of photovoltaic (PV) or concentrating solar power station (CSP) will remain a high cost option compared to fossil fuels. The Iraqi state is expected to add a small amount of solar PV – less than 50 megawatts – by 2035.

The increase in the participation of PV plants in electricity production is expected to have significant economic consequences, such as:

1. Increasing the proportion of investments and industrial and commercial competition, which contribute to the increase of regional capital
2. Increasing the cash reserves by encouraging and activating foreign investments in this field
3. Achieving significant savings in the consumption of fossil fuel sources, which provides the opportunity to benefit from export at international prices instead of selling locally at subsidized prices
4. Activating carbon trading and green certificates in the Iraqi environment sector under the Clean Development Mechanism (CDM)
5. Creating new areas of work at the regional level, in particular with regard to the construction of local industries for renewable energy technologies
6. Reducing dependence on fossil fuel sources, which constitute a heavy burden on the public treasury
7. Supporting the requirements of sustainable development through the exploitation of all energy sources of the countries of the region

This participation also has environmental consequences, including:

1. Reducing pollution and contributing to reducing climate change
2. Taking the advantage of the global carbon trade

As for the social results, the most important are:

1. Fighting unemployment by providing new jobs in the field of renewable energy at the technical, administrative, and legislative levels.
2. Improving the standard of living of individuals by meeting their energy requirements, especially in rural areas, thus reducing the phenomenon of rural-urban migration.

3. Creating jobs directly related to the development of renewable energy and the development and localization of their technologies.
4. Increasing the energy security of Member States, contributing to sustainable development processes.
5. Reducing the phenomenon of poverty in the Arab countries by providing the necessary energy for the poor areas that will create new jobs and improve the social level in these areas.

8.7 Conclusions

The implementation of the strategy relying on renewable energy sources in an integrated and effective manner and achieving its objective requires a clear definition of the responsibilities and follow-up mechanisms. A plan of action should be established for periodic follow-up of all stages of implementation, coordination of cooperation with neighboring countries, and the proposal for continuous development and updating of the strategy. The activation of the strategy of developing renewable energy use can be achieved through:

1. Adopting national policies to create the appropriate climate for the development of renewable energy technologies and the dissemination of their applications on the ground while increasing the contribution of their sources to the energy mix used in sustainable development processes.
2. Strengthening regional and international cooperation mechanisms and sharing experience in this area while promoting awareness of the technical and applied potential of renewable energy systems.
3. Encouraging the private sector to participate in the development of renewable energy systems and uses, with the support of scientific and applied research in the field, leading to the availability of renewable energy equipment at affordable prices.
4. Increasing the reliance on research centers and universities in spreading the awareness on the use of solar cells and in developing the necessary plans and monitoring their implementation.

References

1. Chaichan MT, Kazem HA (2012) Status and future prospects of renewable energy in Iraq. Renew Sustain Energ Rev 16(1):6007–6012
2. Al-Waeely AA, Salman SD, Abdol-Reza WK, Chaichan MT, Kazem HA, Al-Jibori HSS (2014) Evaluation of the spatial distribution of shared electrical generators and their environmental effects at Al-Sader City-Baghdad-Iraq. Int J Eng Technol IJET-IJENS 14(2):16–23
3. Chow TT, Chan ALS, Fong KF, Lo WC, Song CL (2005) Energy performance of a solar hybrid collector system in a multistory apartment building. Proc I Mech E Part A J Power Energy 219 (1):1–11

4. Al-Karaghouli A, Kazmerski LL (2010) Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. Sol Energy 84(4):710–714
5. Austin C, Borja R, Phillips J (2005) Operation solar eagle: a study examining photovoltaic (PV) solar power as an alternative for the rebuilding of the Iraqi electrical power generation infrastructure, Calhoun: The NPS Institutional Archive DSpace Repository, Naval Postgraduate School, Monterey
6. Mahdi AMJ, Reza KS, Kadhem JA, Al-Waeli AAK, Al-Asadi KAH (2017) The effect of Iraqi climate variables on the performance of photovoltaic modules. Int J Scientific Eng Sci 1 (1):7–12
7. Rashid S (2012) Electricity problem in Iraq, HCU- Hamburg REAP WS 2011–2012
8. Bilmes L (2013) The financial legacy of Iraq and Afghanistan: how wartime spending decisions will constrain future national security budgets, HKS Working Paper No. RWP13-006, p 22
9. Doyle P, Jaafar K (2010) Iraq has an opportunity to become a solar leader, available at www.iraqi-datepalms.net/Uploaded/file/SolarEnergyLeader
10. Tanner C (2003) Capturing the sun's energy. Imagine 6(3):12–13. http://muse.jhu.edu/journals/imagine/v006/6.3imagine.pdf. Accessed 25 April 2005
11. Nieuwenhout FDJ, Van Dijk A, Lasschuit PE, Van Roekel G, Van Dijk VAP, Hirsch D, Arriaza H, Hankins M, Sharma BD, Wade H (2001) Experience with solar home systems in developing countries: a review. Prog Photovolt Res Appl 9(6):455–474
12. The International Renewable Energy Agency (IRENA) (2012) Renewable energy technologies: cost analysis series: concentrating solar power. Available at: https://www.irena.org/documentdownloads/publications/re_technologies_cost_analysis-csp.pdf
13. Jasim KK (2015) Study and design of PV/thermal solar collector and their potential in IRAQ. Int J Enhanc Res Sci Technol Eng 4(5):95–103
14. Jallo NIB (2013) Should Iraqis go solar on household level? J Asian Scientific Res 3 (9):903–909
15. RCREE (Regional Center of Renewable Energy and Energy Efficiency) (2011) A guide to the possibilities of Arab countries in the fields of renewable energy and raising the efficiency of production and energy consumption. Available at: http://www.rcreee.org/projects/arab-region-renewable-energy-and-energy-efficiency-guide-daleel
16. Nawawi Z, Aziz AS, Buntat Z, Sidik MAB, Kareem HJ, Aziz MAA, Abdulameer AZ, Jambak MI, Arief YZ (2016) Performance analysis of a VPV/FC hybrid system for generating electricity in Iraq's remote areas. TELKOMNIKA (Telecommun Comput Electron Control) 14 (2):411–422
17. Chedid R, Chaaban F (2003) Renewable-energy developments in Arab countries: a regional perspective. Appl Energy 74(1–2):211–220
18. Dawood* F, Urmee T, Shafiullah GM (2017) The renewable energy household lighting for Chibayish inhabitant’s in Iraq. Renew Energy Environ Sustain 2:15
19. Munir A, Al-Karaghouli AA, Al-Douri AAJ (2007) A PV pumping station for drinking water in a remote residential complex. Desalination 209(1–3):58–63
20. Al-Badri N, Abu Hijleh B (2014) Grid electricity demand reduction through applying active strategies in Baghdad-Iraq, World SB 4, Barcelona
21. Al-Helal A (2015) Solar energy as an alternative energy than the conventional means of electricity generation in Iraq. Int J Invent Eng Sci (IJIES) 3(2):11–14

Authors Brief Biography

Miqdam Tariq Chaichan received his BSc and MSc degrees in Mechanical Engineering from Baghdad University and University of Technology (UOT), Baghdad, Iraq, in 1982 and 1989, respectively. In 1983, he joined Iraqi Republic Railways Enterprise, Iraq, and in 1992–1997, he was appointed as general manager, Engineering Prevue, Baghdad, Iraq. In 1997–1999, he was head of Mechanical Engineering Department, High Institute of Mechanical and Electrical Engineering, Zewara, Libya. In 2003–2005, he was Technical and Commercial Manager, Giad Company, Iraqi branch, Baghdad, Iraq. In 2006–2007, he was coordinator of Automotive Engineering Department, Machines and Equipment Department, UOT, Baghdad, Iraq. In 2007–2009, he was lecturer in Sohar University, Oman. In 2009–2015, he joined Machines and Equipment Engineering Department, UOT, Iraq. In 2016, he joined Energy and Renewable Energies Technology Center, University of Technology, Baghdad, Iraq.

Miqdam is involved in academics and research, since the last 20 years, and is associated with professional organization and engineering societies. He participates in many conferences, symposiums, and workshops. He is a referee for few international journals. Also, he is a referee and organizer for many international conferences and editor of few international journals. He has authored several publications on electrical engineering, including more than 180 papers published in scientific journals and conferences, and two books in refrigeration and air conditioning engineering.

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In 2002, he became a lecturer, assistant professor, and associate professor in the Faculty of Engineering, Sohar University, Sultanate of Oman. Also, he is currently academic visitor at Newcastle University, UK, and visiting scientist in University Kebangsaan Malaysia, Malaysia.

Hussein is involved in academics and research, since the last 20 years and is associated with professional organization and engineering societies such as IEEE, IEE, Elsevier, IAENG, WREN, and WSEAS. He organized and participated in many conferences, symposiums, and workshops. He is a referee in IEEE, WSEAS, AMSE, Elsevier, and IJCSER journals. Also, he is a referee and organizer for many international conferences and editor of few international journals. He has authored several publications on electrical engineering, including more than 135 papers published in scientific journals and conferences, 40 invited talks, and 4 books on power electronics, electrical machines, photovoltaic, and renewable energy. Dr. Hussein is the winner of Sohar University Vice Chancellor Award for Research and Industry.

Also, he is the winner of national and international awards: Tistahil Award, Majan Electricity Company, Oman; the Golden Medal Award, Pecipta'13, Malaysia; and Outstanding Renewable Energy Lab Award, World Renewable Energy Congress XIII, 3–8 August 2014, London, UK; he is an inventor and co-inventor of two patents. Hussein had supervised and graduated more than 35 BSc, 7 MSc, and 2 PhD students under his supervision in Al-Tahady University, Sohar University, Newcastle University, University Kebangsaan Malaysia, and University of Malaysia Perlis.

Dr. Hussein has completed two research projects as principle investigator and co-investigator granted by the Research Council of Oman (TRC). Also, he has new TRC-ORG grant and TRC-FURAP projects. His current research interests are in the areas of photovoltaics, renewable energy, power electronics, power quality, and electrical power system. Hussein is Chairman of the Renewable Energy and Sustainable Technology Research Group in Oman. Dr. Hussein is the team leader of Generation and Storage taskforce in Oman Renewable Energy Strategic Program.

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