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Faculty of Graduate Studies

**A Multi Criteria Decision Approach for
Ranking Renewable Energy Technologies in
Palestinian Territories**

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**This Thesis is Submitted in Partial Fulfillment of the Requirements for
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Dedication

To my father and mother, Munzer Nabulsi and Lubna Arafat, who loved me unconditionally and never gave up in my abilities....Two kisses from me on their foreheads filled with love and respect.

To my beloved husband, Rami Shraim, the one who taught me to never stop learning and be always ambitious even when I doubt myself.

To my second family, my husband's family, for their support and their participation in bearing the burdens. I would not be here without your care.

To my son, Izz Addin, who endured my absence, and my preoccupation with study and work. To my second son, Saif Addin, who shares me the last phase in Master, which is preparation of thesis. Thanks Allah in for your presence in my life.

Thank you for everything.

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الإقرار

أنا الموقعة أدناه، مقدّمة الرسالة التي تحمل العنوان:

A Multi Criteria Decision Approach for Ranking Renewable Energy Technologies in Palestinian Territories

أقر بأن ما اشتملت عليه هذه الأطروحة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد. وأن هذه الرسالة كاملة، أو أي جزء منها لم يقدم من قبل لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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List of Abbreviations

AHP	Analytical hierarchy process
BTL	Biomass to liquid
CBA	Cost to benefits analysis
CI	Consistency index
CR	Consistency ratio
CSP	Concentrated solar power
EIA	US Energy Information Administration
ELECTRE	Elimination and choice translating reality
ENSAD	Energy- Related Severe Accident Database
EPA	Environmental Protection Agency
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LCOE	Levelized Cost of Energy
LPG	Liquefied petroleum gases
MCDA	Multiple criteria decision analysis
MCDM	Multi- criteria decision making
NPV	Net present value
PBP	Pay Back Period
PCBS	Palestinian Central Bureau of Statistics
PEA	Palestinian Energy Authority
PROMETHE	Preference ranking organization method
PSA	Probabilistic safety assessment
PV	Photovoltaic
RE	Renewable energy
REmap	Renewable Energy Roadmap
RI	Random index
RNA	Rank number of alternative
SHPP	Small hydroelectric power plants
SWH	Solar water heaters
TOPSIS	Technique for order preference by similarity to ideal solutions
UN	United Nations
VIKOR	Vlse Kriterijumska Optimizacija I Kompromisno Resenje
WTE	Waste- to- energy

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Abstract

Currently, more than 90% of the electricity utilized in Palestinian Territories relies on imports from outside sources. This dependence, for long periods of time, is not a secure and favorable option. But, there are several renewable energy (RE) technologies that can be served as a solution for future energy supply and electricity shortage; however diversifying energy sources is a complex mission since many parameters are overlapped in this process. This study employed a multi- criteria decision approach based on analytical hierarchy process (AHP) for selection and ranking of eight RE technologies in Palestinian Territories, namely: solar photovoltaic (PV), solar water heaters (SWH), concentrated solar power (CSP), wind, geothermal, biomass, biogas, and waste- to- energy (WTE). AHP model has been used for the first time in energy planning within the Palestinian context. Based on stakeholders' opinion, in addition to bibliographic review of studies related to energy planning, by employing multi- criteria decision tools, the final set of criteria and sub criteria were set. More specifically, the AHP assessment model consists of five criteria (namely, technical, economic, socio- political, environmental, and risk) and twenty two sub criteria and eight RE solutions. Results of the study reveal that SWH is the most promising RE, followed by solar PV, geothermal, wind,

WTE, biogas, biomass, and lastly, CSP. The model also analyzes the performance of each alternative per each sub criteria and end node criteria. Sensitivity analyses have been performed to show how the behavior and overall rankings of alternatives change with respect to the change in the relative weights of criteria. Prioritization and ranking of renewable resources portfolio, findings of the proposed model can be used for long-term energy roadmap and energy policy aiming for sustainability.

Chapter One

Introduction

1.1 Chapter Overview

This chapter provides a general overview of this research. It includes a brief introduction, research problem, research significance, aims and objectives of the research, the research question, and lastly thesis structure.

1.2 General Background

Energy poverty is defined as limited access to electricity and heavily dependence on solid biomass energy for fulfillment of ordinary energy needs of cooking and heating (Samal & Kansal, 2015; Sovacool, 2012). Around 1.1 billion people or about 14% of the earth's population worldwide are without access to electricity grids (International Energy Agency (IEA), 2017). Many of them suffer from poor quality of energy supplied. Nearly 84% of those people with no electricity access are in rural areas and approximately 96% of them place in sub- Saharan Africa and developing Asia (International Energy Agency (IEA), 2017). According to (IEA et al., 2010; IEA, 2017; United Nation Foundation, 2011), more than 2.8 billion people, 38% of the world's population, rely on solid fuels such as wood, charcoal and waste for heating, cooking and their household's energy needs. While the number of people depending on biomass for cooking is smaller in sub- Saharan Africa than in developing Asia, their share of the population is higher: 80% in sub- Saharan Africa, compared with 43% in developing Asia (International Energy Agency (IEA), 2017).

High reliance on the conventional source of energy leads to harmful effects on environment due to greenhouse emissions and global deforestation (Sovacool, 2012).

Energy is the main engine for achieving economic, social, environmental, sustainable development and improved quality of life for different households (El Char & Lamont, 2010). Therefore, energy plays a key role in the economic and social development, and stands as a barrier in the way of environmental and sustainable development. Given rapid technological development, increased global population, and improved standards of living, demand on renewable energy (RE) sources has increased over time (Abu- Madi & Rayyan, 2013). Energy plays a crucial role in sustainable development for the process of production and manufacturing, this is why increased attention must be given to find RE sources that are not exhausted when consumed (Manzano- Agugliaro et al., 2012). Moreover, the main drivers for searching alternative energy sources are fossil fuels depletion, and climate change issues (Mezher, Dawelbait, & Abbas, 2012). Burning of fossil fuels (coal, oil, and natural gases) release many toxic and harmful gases (SO_2 , CO, NO_x , HC and CO_2) which cause a great damage to the surrounding environment (Bose, 2013). World has limited reserve of fossil fuels and large- scale use will lead to exhausting and increasing its related environmental problems (Manzano-Agugliaro, Hernández, & Zapata, 2010). Access to RE has many pros in developing countries, including an increase of energy services in rural, remote areas, and is linked with general improvement of economic, social and environmental sectors

(Thiam, 2011). Dependence on RE worldwide is connected with effective approaches to sustainable development; they have a high potential to be cost effective, not causing deterioration to the environment and designed to be accepted by the local communities (Castellano et al., 2015; Hepbasli, 2008). RE technologies have increasing applications in various fields including residential, commercial, agricultural and industrial applications (Fernández- García et al., 2015; Sarver et al., 2013). RE leads countries to the prosperity and helps to achieve their strategic goals in securing reliable and affordable source of energy, encourage development and reduce energy price volatility (Casanova- Peláez et al., 2015). Decade 2014- 2024 has been announced as the "Decade of Sustainable Energy for All" by United Nations (UN) general assembly in order to ensure access for all people to reliable, renewable, clean, and affordable sources of energy (United Nations (UN), 2014).

Many natural and political factors adversely affect energy sector in Palestinian Territories. Most importantly, inability for the production of fossil fuels due to the dearth of natural resources in Palestinian Territories. There is no interconnection between East Jerusalem and West Bank and Gaza strip. Gaza's isolation poses significant political and technical obstacles for transferring, storing, exporting, and importing energy (Abu Hamed, Flamm, & Azraq, 2012). In addition, East Jerusalem and West Bank have been exposed to administrative divisions due to political issues and this in turn impedes the development of energy sector and local economy. Palestinian Territories depend highly on imported electricity and

petroleum products. In 2018, more than 93% of the electricity consumed in Palestinian Territories is imported (Palestinian Central Bureau of Statistics (PCBS), 2018), with the majority originating in Israel and with marginal percentage from Jordan and Egypt. Moreover, Israel controls energy imports into Palestinian Territories and thus hinders open trade between Palestinian Territories and other regions. Cost of the energy in Palestinian Territories is the highest in the Middle East (Abu Hamed et al., 2012). Many investors are prohibited from making industrial investments or energy projects due to the political instability (Abu Hamed et al., 2012). As a result of these circumstances there is no physical continuity between Palestinian Territories. West Bank has been divided into multiple zones called A, B, and C due to Oslo Peace agreement where area C reflects full Israeli civilian and military control. Around 60% of the regions in the West Bank are classified as C regions. These political constraints hinder the development of energy sector and limit the utilization of potential renewable resources in Palestinian Territories.

Non availability of natural resources, high density population, financial crises, high energy imports, economic situation of the people, and political instability raise the demand on energy. Therefore, searching for alternative sources of energy is very important for future generations that are concentrating on the renewable source of energy. Transition to sustainable energy sector in Palestinian Territories can be realized by RE (International Renewable Energy Agency (IRENA), 2014).

In recent years, energy planning has become more complex due to the inclusion of many participants (investors, community, academicians, governments etc.) and due to the combination of various objectives. In the decision- making process, multiple criteria decision analysis (MCDA) is proved to be an efficient tool since it considers the preference and interest of the multiple elements. In order to meet the growing demand for energy and to have an energy system with a vision of sustainability, sufficient energy planning that takes into account economic, technical, environmental, social, political, and risk issues should be considered.

The goal of this research is to use multi- criteria decision making approach based on analytical hierarchy process (AHP) for prioritizing criteria, sub- criteria and alternatives for RE generation in Palestinian Territories. Eight technologies of RE's are analyzed in this research namely: solar photovoltaic (PV), concentrated solar power (CSP), solar water heaters (SWH), wind energy, biomass, biogas, waste- to- energy (WTE) and geothermal energy. The criteria used in this research can be classified as technical, economic, socio- political, risk, and environmental criteria.

1.3 Problem Statement

There is a trend in various developed and developing countries of the world that aims to develop policies to take advantage of all types of RE sources and to increase the rate of investment in these sources, as a way to preserve human health and environment. In addition, to find new sources and forms

of energy that have the potential to continue and renew in order to face high demand of energy and rapid economic growth. These alternatives would also improve the quality of human life, global and local environment.

Palestinian Territories suffers from the scarcity of traditional energy sources, such as oil and gas, and from its high prices, that equal the most expensive cities in the world. Moreover, the Israeli authorities control the amount and prices of fuels, when they are allowed to enter, and when they are prohibited. Inspired by this suffering, Palestinians seek to overcome this dilemma through utilization of RE sources as they can reduce their dependence on Israeli fuels. The clearest example of this was the fuel crisis that Gaza Strip suffered of in the middle of 2013 which negatively affected the lives of people, especially the health and transportation sectors. The Palestinian tendency to rely more on RE sources comes in line with the growing global trends for the exploitation of alternative energy sources. The Palestinians have succeeded to some extent by using solar energy, especially in obtaining hot water since the mid- 1970s. However, converting solar energy has limited experience, linked to research issues or the activities of donor agencies to help residents of disadvantaged regions. There are initial attempts to exploit wind energy, biomass, biogas, as well as geothermal energy.

The Palestinian Authority supports all individual and collective initiatives and attempts in these fields, but the road is still in its infancy. There are many obstacles for achieving clean energy revolution in Palestinian Territories, perhaps the most prominent one is the scarcity of Palestinian research and studies dealing with RE issues, lack of maps showing the movement of winds and places of seasonal sunshine, soil characteristics, as well as the lack of devices to implement field measurements of heat distribution in ground layers, the high cost of equipment and the high cost of storing surplus energy. Consequently, as there is a need for studies and researches specific for Palestinian Territories, this study attempts to provide a practical contribution by ranking and prioritizing RE sources for sustainable development by using AHP methodology.

in this research, MCDM approach based on AHP methodology has been used to rank and analyze renewable energy technologies from different perspectives, namely: technical, economic, socio- political, environmental, and risk. This analysis will help decision makers in energy field to understand the performance of each RE technology. Also, this will help them to put a sustainable energy plan for the next years.

1.4 Research Significance

This study provides a road map for decision makers in Palestinian Territories to rank different RE technologies for developing a sustainable generation system. Green energy sources protect human health, preserve the natural environment, reduce the number and intensity of natural

disasters resulting from global warming, protect groundwater, rivers, seas and fisheries from pollution, improve human life and reduce poverty and secure new job opportunities.

Many researches attempted to provide an overview of the current energy situation in Palestinian Territories by analyzing the challenges, benefits and potential impact of developing RE sources, and through determining the anticipated weakness, strengths and application of potential RE projects (Abu Hamed et al., 2012; Basel & Yaseen, 2007; Juaidi et al., 2016). Mahmoud & Ibrik (2006) studied the techno- economic feasibility of power supply of remote villages in Palestinian Territories by diesel generators, PV- systems and electric grid. Moreover, no research previously has ranked and assessed RE sources by using MCDM. Thus, this study will provide a framework based on AHP to prioritize RE alternatives, criteria and subcriteria as a support tool for developing sustainable energy system in Palestinian Territories.

This study adopted multi- criteria analysis following AHP for the assessment of different green technologies. Developing an MCDM framework would simplify inclusion of political, environmental, economic, and social criteria in the decision- making process towards shaping of sustainable energy sector rather than depending on one dimension to assess different alternatives. Involvement of various stakeholders in decision making process increases the results credibility, acceptability and share of responsibility.

1.5 Research Objectives

The main objective of this research is to provide contributions in two aspects mainly, as follows:

1. **Practical contribution:** to assist decision makers, researchers, and any party responsible for energy planning in Palestinian Territories. Firstly, identifying the best renewable alternative for sustainable development through evaluation of the overall system mix for energy suppliers. Secondly, introducing a framework that is capable of dealing with multiple goals, objectives and provides promising solutions since energy planning is characterized by complexity and multifunctional aspects. Finally, determining to what extent each energy technology contributes to sustainable mix profile.
2. **Theoretical contribution:** to address the gaps found in the literature regarding the scope of this study. This study proposes a framework based on AHP for prioritizing criteria, subcriteria and eight technologies of renewable power generation in the Palestinian regions namely: solar PV, CSP, SWH, wind, biomass, biogas, WTE and geothermal as a support for decision making in the process of energy planning. To the best of our knowledge, there is no previous research used AHP for ranking RE technologies from different aspects including: socio-political, environmental, technical, economic, and risk criteria in the context of Palestinian Territories.

1.6 The Research Question

Drawing on previously- discussed literature, this study aims to establish a multi- criteria hierarchy for the selection and ranking of renewable alternatives in Palestinian Territories to achieve energy security and sustainable development. The main research question of this study is summarized as:

RQ 1: What is the best ranking of RE technologies from technical, economic, social- political, environmental and risk perspectives for sustainable development in Palestinian Territories?

1.7 Thesis Structure

This thesis includes six chapters. The first chapter “*Introduction*” introduces the thesis subject through a brief background overview. It also encompasses the research problem and the importance to support this research. Also, it clarifies the main objectives of the research, and the research question.

The second chapter “*Literature Review*” introduces a literature review and summarizes studies that addressed RE potential in Palestinian Territories, RE targets, MCDM tools in energy planning, and previous studies which support the thesis formulation. In addition, a broader view was taken to look into how RE may help in generating sustainable energy plans. Also, it discusses the expected drivers, and benefits of RE strategies on long-run.

The third chapter “*Research Methodology*” presents the methodology that has been followed in this research through discussing of data collection process, the population targeted, sampling process, the instrument development for data collection and the data analysis approach.

The fourth chapter “*Prioritization*” presents the procedure that was followed in order to transform quantitative and qualitative data into comparison matrices, which form the basic blocks to start data analysis and prioritize energy alternatives.

The fifth chapter “*Results and Discussion*” discusses the results obtained after analyzing the data and generating relative weights of RE alternatives throughout the hierarchy of the proposed model. Finally, the sixth chapter “*Conclusions and Recommendations*” gives brief conclusions on results with a set of recommendations and future research suggestions.

Chapter Two

Literature Review

2.1 Chapter Overview

This chapter focuses on three primary dimensions. First dimension describes the energy situation in Palestinian Territories. It provides a clear image of energy consumption, energy sources, classification of the consumed energy, and average price of different types of energy. Also, it presents the RE targets for year 2020. The second dimension presents the RE potential in Palestinian Territories that could be exploited to establish a sustainable energy system. The final one presents an overview of the tools that were used in energy planning and explains the fields of its applications, as well as it mentions some studies that adopted multi- criteria techniques.

2.2 Energy Sector Situation in Palestinian Territories

Energy in Palestinian Territories is generated from three primary sources, which are: first the energy generated by petroleum products, second by electricity, and third by RE. Figure (2.1) shows the main energy sources in Palestinian Territories. The majority, 58%, are fossil fuels, such as liquefied petroleum gases (LPG), gasoline, diesel, fuel oil, lubricants, bitumen and kerosene, while the remaining 42% distributed as 29% for electricity, and 13% for RE sources. Abu Hamed, Flamm, & Azraq (2012) noticed that energy consumption in Palestinian Territories is lower than its neighboring countries.

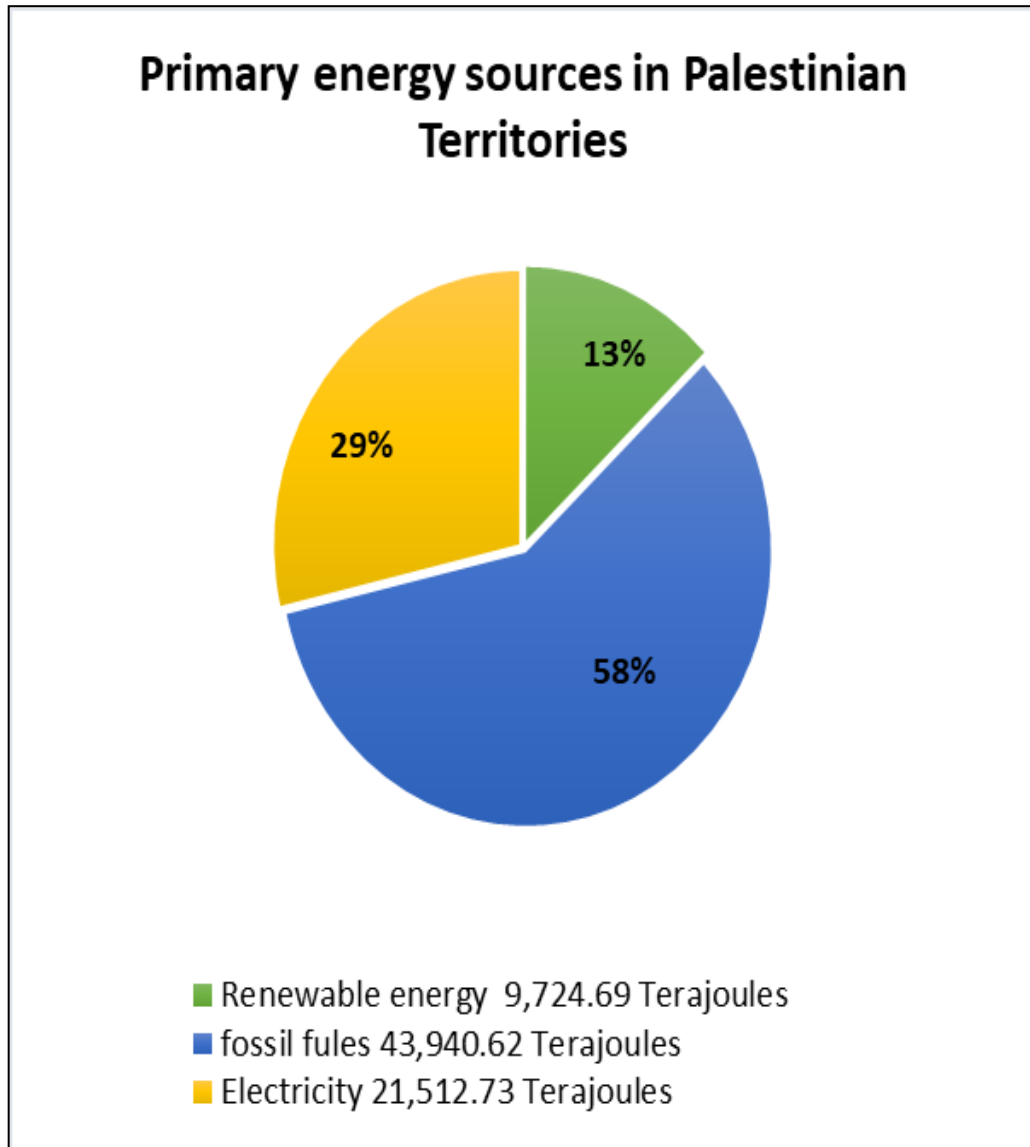


Figure (2.1): Primary energy sources in Palestinian Territories. Source: (Palestinian Central Bureau of Statistics (PCBS), 2018).

Figure (2.2) illustrates that Diesel and Gasoline are the most fossil fuels consumed in Palestinian Territories with a weights of 55% and 23%, respectively. After that LPG with a weight of 18%, then Bitumen by 3%, and finally with 1% percent are Oils and Lubricants, Fuel Oil, and Kerosene.

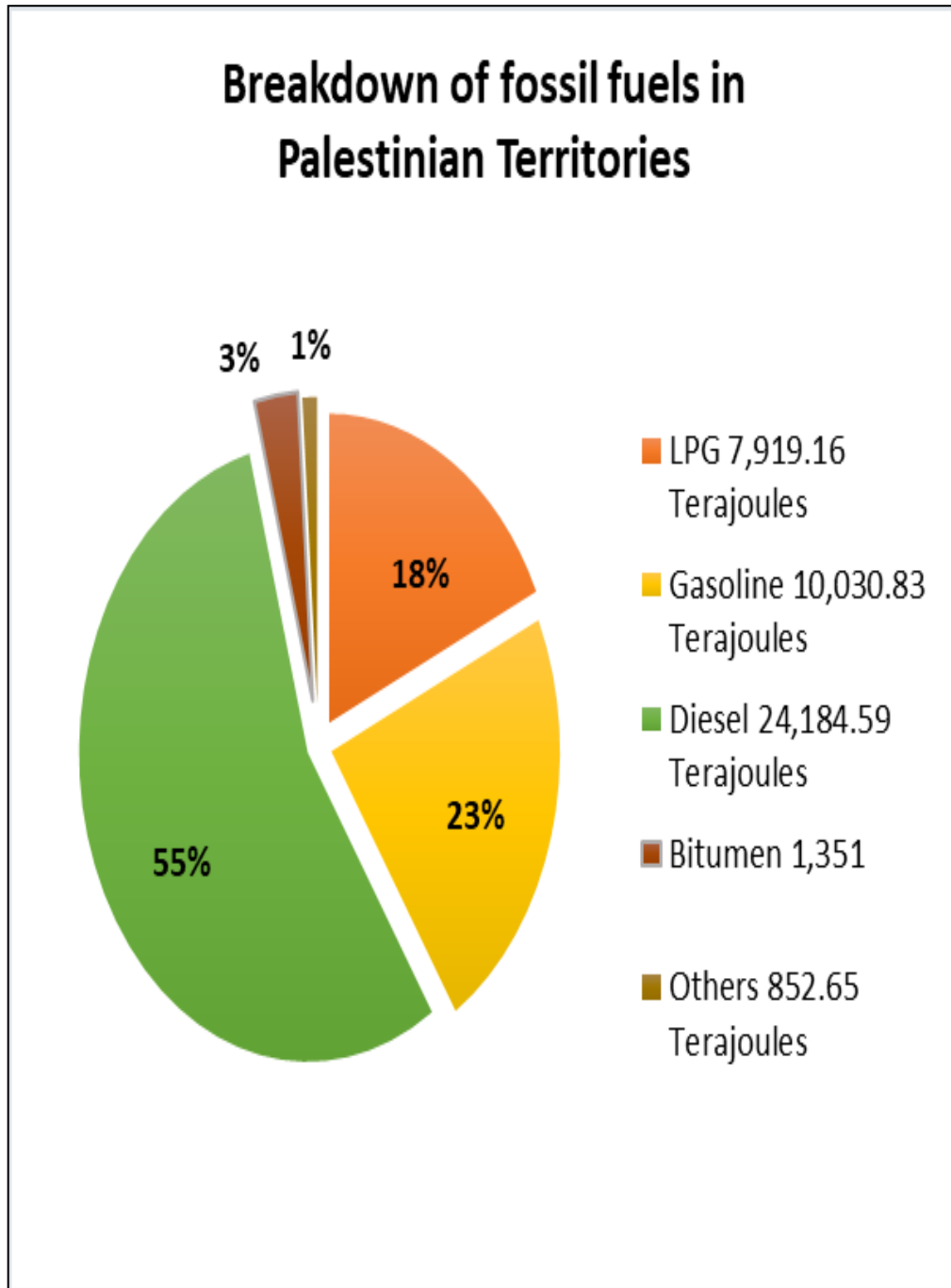


Figure (2.2): Breakdown of fossil fuels in Palestinian Territories. Source: (Palestinian Central Bureau of Statistics (PCBS), 2018).

Figure (2.3) demonstrates that solar energy from solar water heaters accounts for 59% of the RE produced in Palestinian Territories, while Biomass from Olive Cake, and wood and Charcoal accounts for 41%.

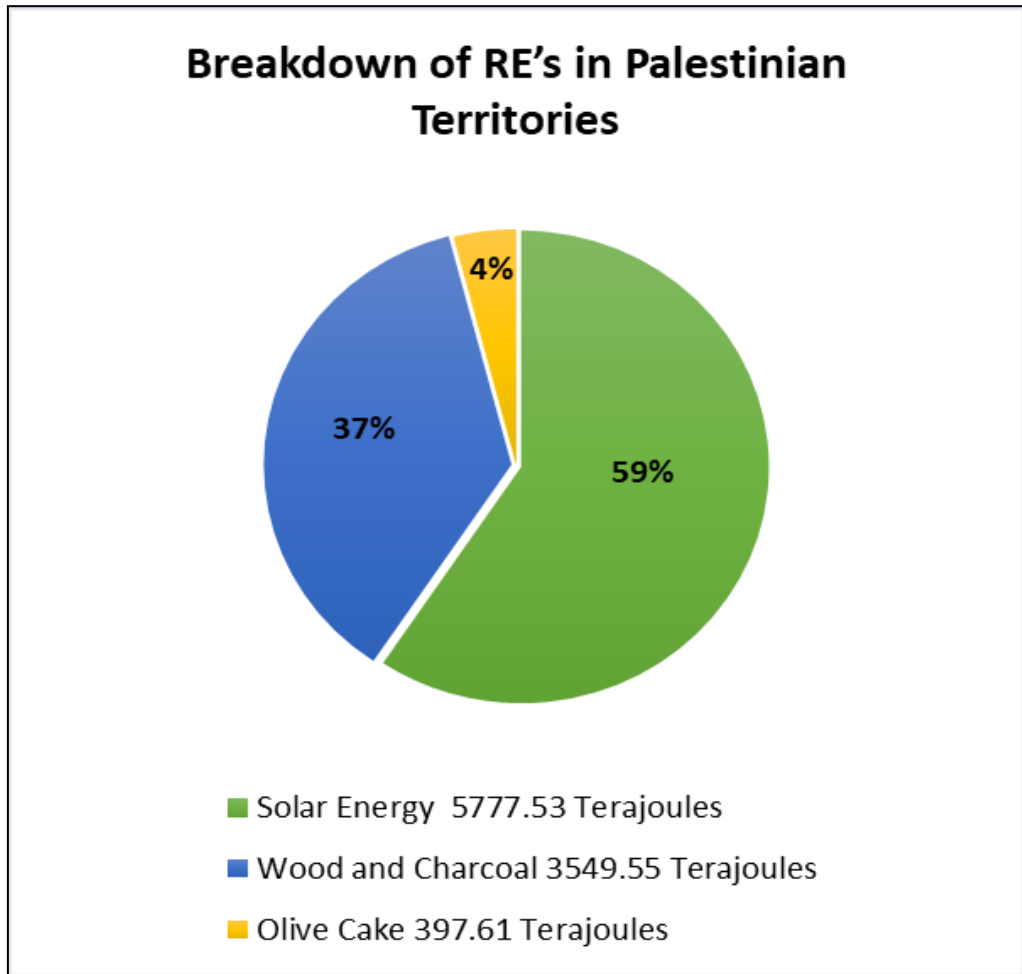


Figure (2.3): Breakdown of RE's in Palestinian Territories. Source: (Palestinian Central Bureau of Statistics (PCBS), 2018).

Most of the energy consumed in Palestinian Territories is imported from Israel, which is the main feeder, while the rest of the energy is imported from Egypt and Jordan. Egypt feeds Gaza Strip and Jordan feeds West Bank. Figure (2.4) presents quantity and source country of the electricity purchased in Palestinian Territories in year 2018: 4.11% of the electricity was produced by the Palestinian Electricity Company, while the remaining 95.89% was imported from Egypt, Jordan, and Israel; 0.95% from Egypt, 1.43% from Jordan, and 93.87% from Israeli Electricity Company.

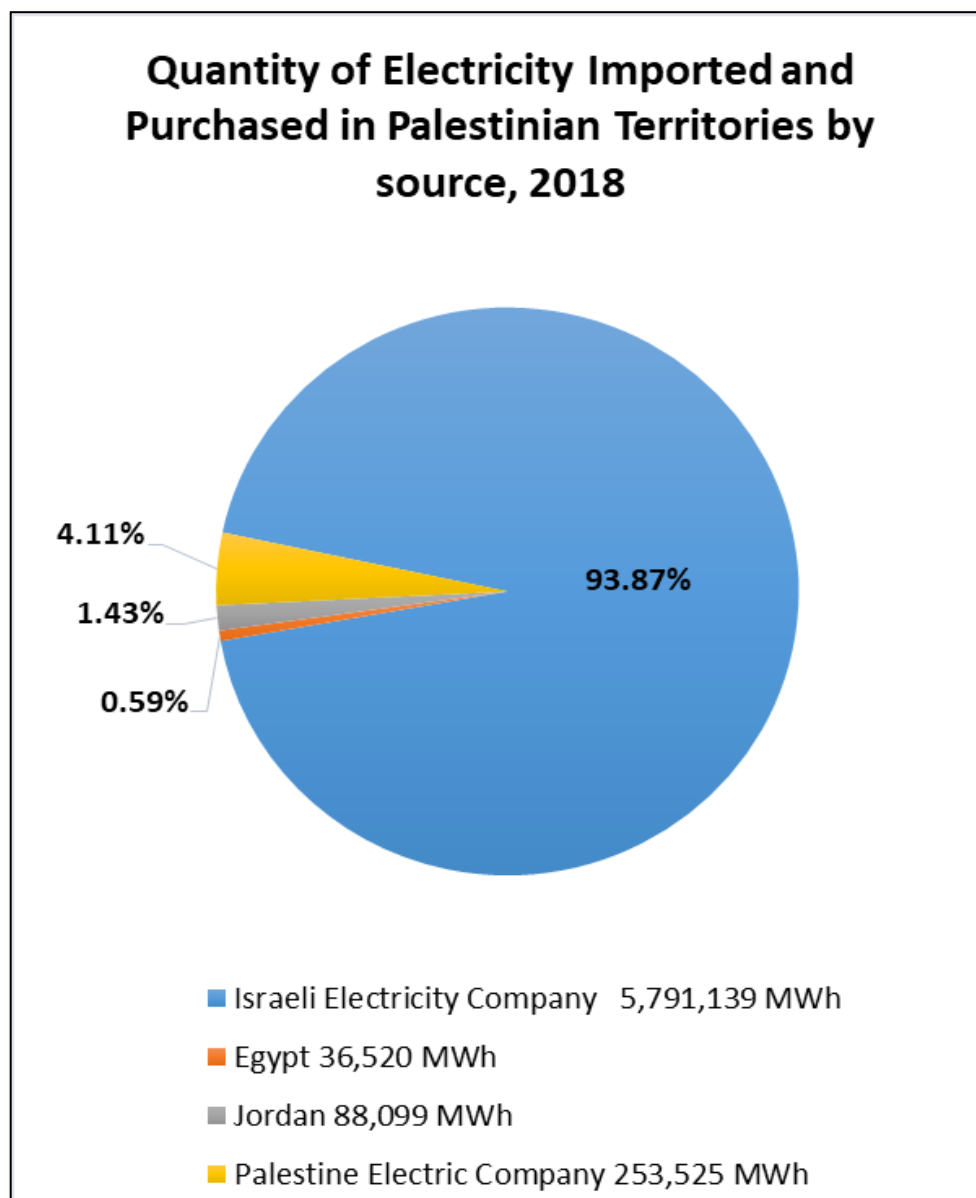


Figure (2.4): Quantity and country of electricity purchased and imported in Palestinian Territories, 2018. Source: (Palestinian Central Bureau of Statistics (PCBS), 2018).

Quantity of available electricity in Palestinian Territories by year and source of electrical energy in year 2018 is illustrated in Figure (2.5). About 93% of electricity consumed in Palestinian Territories is imported, 4% is purchased from Palestine Electric Company, while 3% is produced from RE sources and self- generation systems.

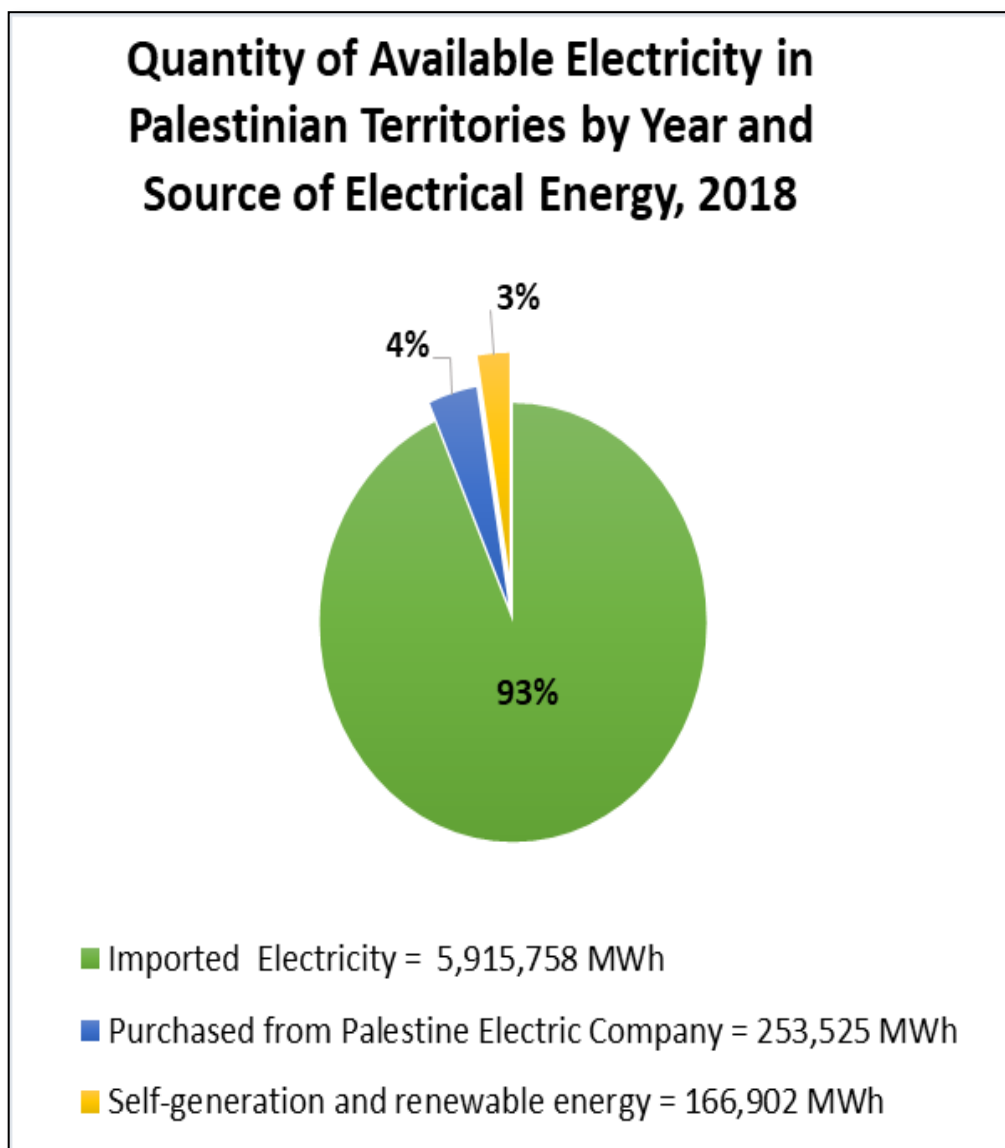


Figure (2.5): Quantity of available electricity in Palestinian Territories by year and source of electrical energy, 2018. Source: (Palestinian Central Bureau of Statistics (PCBS), 2018).

Palestinian Territories depend highly on external energy supply. It is obvious from Table (2.1) that almost any type of energy is imported. Electricity imports in Palestinian Territories by country in year 2018 is shown in Table (2.1), with a total amount of 5,915,758 MWh, distributed in 4,864,610 MW h for West Bank and 1,051,148 MW h for Gaza Strip.

Table (2.1): Imported energy in Palestinian Territory by type of energy and region, 2018.

Region	Type of Energy							
	Electricity (MWh)	Gasoline (Thousand Liter)	Diesel (Thousand Liter)	Fuel Oil (Thousand Liter)	Kerosene (Thousand Liter)	LPG (Ton)	Bitumen (Ton)	Wood and Charcoal (Tons)
Palestinian Territory	5,915,758	305,986	646,474	6,484	1,008	167,424	33,607	3,725
West Bank	4,864,610	281,410	458,400	6,186	1,008	120,038	33,607	3,193
Gaza Strip	1,051,148	24,576	188,074	298	0	47,386	0	532

Source: (Palestinian Central Bureau of Statistics (PCBS), 2018).

The average annual prices for different types of energy in year 2018 are highlighted in Table (2.2). According to Abu Hamed, Flamm, & Azraq (2012), cost of the energy consumed in Palestinian Territories is the highest in the Middle East.

Table (2.2): Average consumer prices in the West Bank and Gaza strips for selected energy types, 2018.

Region	Energy Type				
	LPG (NIS/12 Kg)	Kerosene (NIS/Liter)	Coal (NIS/Kg)	Gasoline ⁽²⁾ (NIS/Liter)	Diesel (NIS/Liter)
West Bank	65.97	5.85	7.08	6.23	5.85
Gaza Strip	61.88	5.02	5.87	5.81	5.02

Source: (Palestinian Central Bureau of Statistics (PCBS), 2018).

Electricity consumption in Palestinian Territories is increasing overtime and this seems clear as presented in Figure (2.6). Electricity consumption has been increased from 4,632,169 MWh in year 2010 up to 6,336,185 MWh in year 2018. Energy sector strategy has showed that energy sector is characterized by rare resources and inability to fully utilize currently available recourses leading it to highly reliance on importing from Israel (AuthsORITY PN, 2011). The Palestinian dependence on Israel for the majority of its fuels is complex not only within the political context but also due to the fact that energy consumption in Palestinian Territories is an additional load on Israeli production and distribution system (Juaidi et al., 2016)

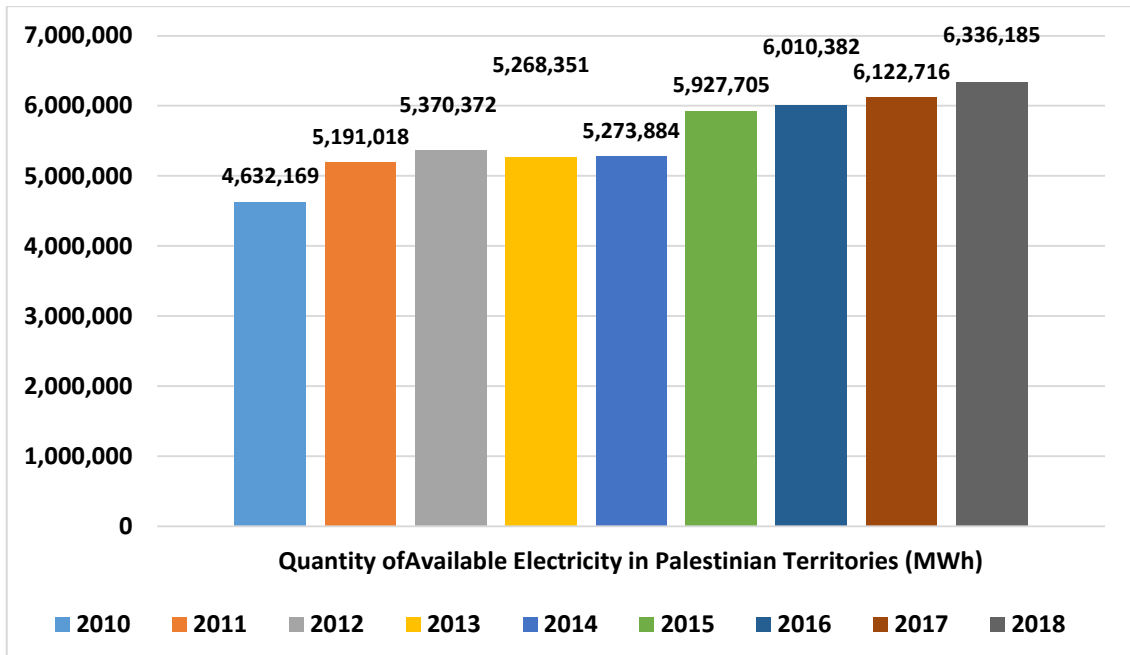


Figure (2.6): Quantity of Available Electricity in Palestinian Territories by Year, 2010-2018. Source: (Palestinian Central Bureau of Statistics (PCBS), 2018).

2.3 Palestinian Energy Strategy for Year 2020

Palestinian Energy Authority (PEA) aims to generate 10% of electricity through RE sources by the year 2020, distributed as follows: 34.6% from PV, 33.8% from wind energy, 16.2% from WTE, and 15.4% from CSP (RCREEE, 2012). This will reduce the dependence upon foreign sources, and ensure the security of energy supply. Table (2.3) illustrates RE targets for year 2020 and MW expected to be installed. Figure (2.7) displays a comparison between the current installed capacity in Palestinian Territories for year 2012 and the expected RE targets for year 2020.

Table (2.3): RE targets for year 2020.

	Wind	PV	CSP	WTE	Total
MW	44	45	20	21	130

Source: (RCREEE, 2012).

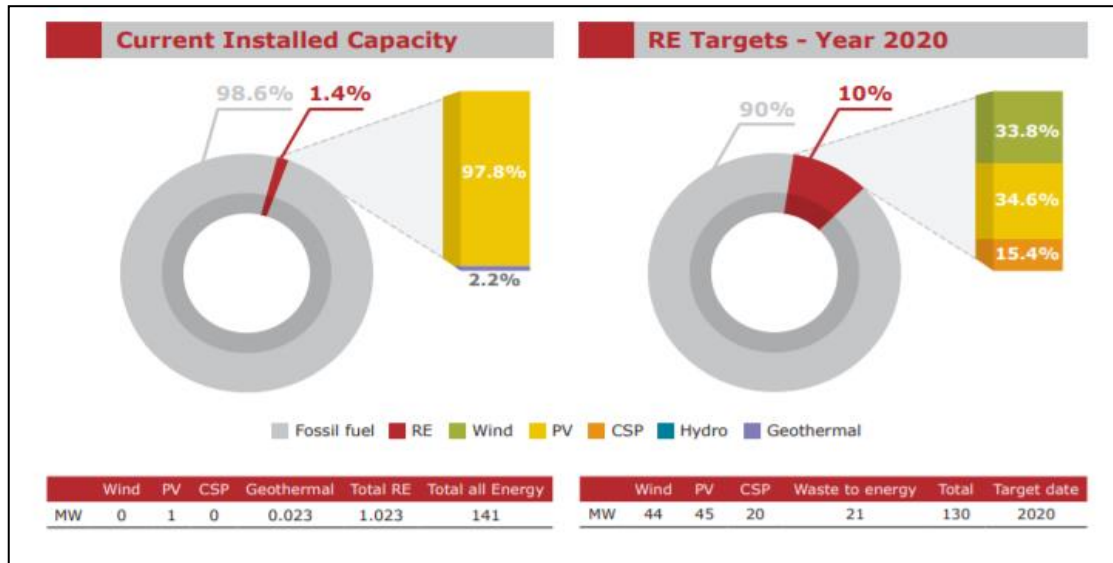


Figure (2.7): RE Country Profile for Palestinian Territories. Source: (RCREEE, 2012).

2.4 Renewable Energy Potential and Opportunities in Palestinian Territories

In contrast to the lack of traditional energy sources as petroleum and natural gas derivatives on Palestinian regions, there is a high potential for developing renewable energies, mainly for solar, wind, biomass, and geothermal. Palestinian energy security depends on the development of its own energy sources. All resources of knowledge, sources, and technologies are available to enrich this field, even with many political, technical, and financial constraints.

2.4.1 Solar Energy

Palestinian Territories have more than 3000 sunshine hours per year and high annual solar radiation estimating to 5.4 kWh/ m²/ day on horizontal surface. High radiation levels: 5.40– 5.98 kWh/ m² per day are received in the Jordan's valley region. The solar radiation ranges on the horizontal

surface from its minimum value in December, $2.63 \text{ kW h/ m}^2 / \text{ day}$ up to its maximum value in June, $8.4 \text{ kWh/ m}^2/ \text{ day}$. Since these estimates are considered high, it makes Palestinian Territories one of the best areas in the utilization of solar energy for both large scale energy production and stand-alone system. Moreover, it makes investment in this aspect possible, and even economically feasible. The highest solar radiation in year 2010 was recorded in Salfeet, then Ramallah, Hebron, and finally in Tubas with the following respective values: $5.65 \text{ kW h/ m}^2/ \text{ day}$, $5.5 \text{ kW h/ m}^2 / \text{day}$, $5.14 \text{ kW h/ m}^2 / \text{ day}$, $\text{kWh/ m}^2/ \text{ day}$ (Juaidi et al., 2016).

Many applications can be employed for harnessing solar energy such as water heating, water desalination, water pumping, drying of crops vegetables and fruits and for electrification of many rural areas and villages that are remote from electrical grids, and in areas where electricity is not available during 24 h a day.

Results of previous research showed that exploitation of PV system for electrification of remote and rural areas is considered more feasible and profitable than diesel powered electric generators or extension of electric grid. Energy authority and decision makers in Palestinian Territories should seriously consider use of PV systems for many reasons, including:

- Reducing dependence on external resources to provide the needed energy;
- Providing flexibility and security to the system power supply in Palestinian Territories;

- Supplying energy to public utilization, settlements, rural and isolated areas that don't have electric grid or it will not be connected to it in future to meet their energy demand;
- Alleviating damage to the environment by reducing CO₂ emissions by using RE over fossil fuels, and reducing problems related to the reserve depletion of traditional energy sources.

Three solar energy technologies are explained in this research, including solar water heaters (SWH), solar photovoltaic (PV), and concentrated solar thermal, which is also known as concentrated solar power (CSP). Solar water heaters are a very popular technology in Palestinian Territories to generate hot water. It is utilized to convert solar energy into heat through solar collectors, and solar tanks. Solar PV technology depends on the effect of photovoltaic that exists in semiconductors to convert solar energy into electricity. On the other hand, CSP technology concentrates on solar energy by employing reflectors or mirrors to heat fluids that are used to generate electricity.

Cost of electricity generated by PV technology has decreased over years due to the technological advancement and high scale production whereas the cost of CSP technology is still high comparable with solar PV.

In contrast to CSP, PV technology does not work in the absence of both direct and diffuse solar radiation. So, it can't cover energy demand in this period. Storing energy that is generated by PV units is expensive.

However, CSP is expected to gain increase level of use and application in the coming years. According to International Energy Agency (IEA) (2015), the utilization of CSP technology will keep increasing to cover 11% of the total global installed capacities.

2.4.2 Biomass Energy

Biomass is a strategic source for energy generation for both developed and developing countries. This type of energy can be planted anywhere. Biomass provides both an economic fuel choice and a disposal mechanism of industrial organic, agricultural, and municipal wastes. The main disadvantage of biomass is that burning biomass emits CO₂, even though biomass combustion is considered to be “carbon- neutral” because carbon is absorbed by plant material during its growth, thus creating a carbon cycle (International Energy Agency(IEA), 2006).

Traditional use of biomass is mainly used for cooking and heating purposes, while the modern use of biomass energy is for the production of steam, electricity, and liquid biofuels. Bioenergy contributed an estimated 12.4%, or 46.0 EJ (Appavou et al., 2019), to final energy consumption as of the end of 2017, and about 8% of Palestinian energy supply (Abu Hamed et al., 2012).

Palestinian Territories is considered as an agricultural country, since this economic activity is the dominant. As a result, Palestinian regions have the potential for biomass energy. Different types of plants in West Bank and Gaza Strip can be used for the production of bioenergy. Crops can be

categorized as fields' crops (wheat and barley), fruit trees, and vegetables (Butterfield, 2000).

Food processing wastes from Agro- Industry and agricultural residue are considered an important source of biomass. Some of the main vegetables in Palestinian Territories are: peas, pepper, carrot, potatoes, lettuce, corn, okra, pumpkins, cowpeas, turnip, radish, cucumber, onion, eggplant, beans, spinach, sugar beet, thyme, garlic, tomato, musk melon, and water melon. There are many studies that provide a prediction of the heating value of these kind of biomass (Callejón-Ferre et al., 2011), and another research states that extraction of this type of energy can be used for electrification through gasification process (Manzano, 2007). Biofuels from agricultural residue (Lingo-Cellulosic-Feedstock) can be generated through a biomass to liquid (BTL) by thermo- chemical process to produce biodiesel or through a biochemical process to produce ethanol (Juaidi et al., 2016). Various fruit trees in Palestinian Territories can be used as lignocellulosic feedstocks as almond, citrus, apple, banana, apricot, pear, date palm, nuts, guava, figs, and olives (Juaidi et al., 2016). Also, the heat generated from this type of plant is explained in many research (Vargas-Moreno et al., 2012). Combustion of olive cake can be utilized for generating nearly 1.3% of all electricity consumption in Palestinian Territories (Abu Hamed, Ismail, & Alshare, 2017).

According to (United States Environmental Protection Agency (EPA), 2016), WTE is the process of converting waste into various forms of energy such as electricity, heat, and fuels through number of processes including incineration, pyrolysis, landfill gas recovery, anaerobic digestion, and gasification.

2.4.3 Wind Energy

Wind power is domestic, clean, and environmentally- friendly resources for electricity generation (Montoya et al., 2014). Kitaneh, Alsamamra, & Aljunaidi (2012) stated that worldwide capacity of wind power generators was 94 GW, nearly 1% of worldwide electricity use, as illustrated in prior researches. Wind power has the potential to satisfy both large scale and small- scale applications (Nan et al., 2013).

Effective utilization of wind power for electricity generation entails an accurate and detailed knowledge of wind speed, wind energy, and topographical features of the land being studied (Juaidi et al., 2016). The distribution of wind velocity is imperative for the design of power generators, wind farms, and agricultural applications as irrigation (Abu Hamed et al., 2012). For accurate and good wind energy results, long term measurements of wind speeds must be obtained.

Dearth of traditional energy resources as shown (Kitaneh et al., 2012) forces decision makers in Palestinian Territories to search for natural resources as wind energy for the production of non- traditional energy. By looking on wind energy resource mapping of Palestinian Territories, De

Meij et al. (2016) draw that wind energy all over Gaza Strip is not sufficient to be used at any level. However, Yaseen (2009) explained that use of wind potential in various locations in Palestinian Territories, where electricity is not always available, could be feasible.

Palestinian Territories are characterized by a moderate wind speed where the annual average speed of about 4–6 m/s (Kitaneh et al., 2012). Turbines can operate effectively at wind speed values that is higher than this ranges of 4–6 m/s (Adekoya and Adewale, 1992; Mathew, 2006). Gaza Strip has low annual average of wind speed varying in the range of 2.5–3.5 m/s. Moreover, Jordan valley in Jericho is characterized by a very low wind speed throughout the year, with an annual average of about 2–3 m/s. But, the hilly regions in Palestinian Territories such as Nablus, Jerusalem, Hebron, and Ramallah have wind speeds of an annual average of about 4–8 m/s (Juaidi et al., 2016). Locations with a potential to exploit wind energy can be used for electricity generation in areas where diesel generators are used for electrification, or in areas that is far away from electric grids.

2.4.4 Geothermal Energy

Geothermal energy is considered as a green, renewable, local, and low-cost source of energy that requires many research and studies in the geothermal field (Fridleifsson, 2001). Fossil fuels can be substituted for geothermal energy for its ability to supply energy that is: stable and available on demand (Schiermeier et al., 2008), green and help to reduce greenhouse gas emissions (Barbier, 2002).

The number of literatures related to geothermal potential in Palestinian Territories is low when compared to other RE sources (Juaidi et al., 2016). Palestinian Territories owns promising supplies of geothermal energy especially in Gaze Strip and north of Palestinian Territories (El-Kilani & Zaid, 2015).

Geothermal energy can be used in Palestinian Territories mainly for heating and cooling purposes through utilization the stable temperature of the ground at specific high (Hamed, Flamm, & Isma'il, 2012). MENA geothermal is the first known project implemented at Ramallah in West Bank at a residual building. The company provides an evidences that this project has led to decrease in heating and cooling costs by more than 70% with a payback period of 4.5 years (Yaseen, 2009).

2.5 Multiple Criteria Decision Analysis

In recent decades, energy planning has been developed to contain both quantitative and qualitative aspects so, it is not sufficient to just use single indicator as net present value (NPV) to attain a system with a perception of sustainability. Shattan (2008) and Cavallaro (2009) showed in their studies that merely depending on financial indicators as cost to benefits analysis (CBA) leads to prioritize different alternatives as per one dimensions and neglecting others. Evaluation of energy planning problems by using financial means requires that each indicator should have a monetary value. Many indicators in energy planning cannot be translated into numeric value such as effect on human health and social acceptance. As a result, multi-

criteria decision making (MCDM) has become the prominent to tackle problems related to use single- dimensional index for long- term energy source planning.

Many parties are participated in the process of energy planning towards sustainability, including policymakers, investors, academics, regulators, consumers, and environmental interest group. Each one of them has different point of view regarding energy design. The process of choosing the best RE projects to achieve sustainable objectives is too complex since there are many goals resulting from various decision makers. This represents the emerging need for a tool that is capable to handle these differences and make tradeoffs since there is no unique alternative that realizes all criteria jointly (Cristobal & Ramon, 2012). MCDM is used to apprise the overall system mix for energy alternatives to select the best power suppliers for sustainable purposes (Brand & Missaoui, 2014).

MCDM, a branch of operation research, consists of a number of methods. The most common ones are multi attribute utility theory (MAUT), preference ranking organization method (PROMETHE), Vlse Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR), elimination and choice translating reality (ELECTRE), technique for order preference by similarity to ideal solutions (TOPSIS), weighted product method, weighted sum method, and analytical hierarchy process (AHP) (Al Garni et al., 2016; Kumar et al., 2017). In 2010, Kaya & Kahraman used AHP and VIKOR for RE planning in Turkey. In (Amer & Daim, 2011a), AHP was

applied for prioritizing antithetical RE sources in Pakistan. Streimikiene et al. (2012) adopted TOPSIS for ranking sustainable electricity production technologies. ELECTRE was employed in (Georgopoulou, Lalas, & Papagiannakis, 1997) for energy planning. In (Danae Diakoulaki & Karangelis, 2007), PROMETHEE was utilized to check electricity development scenarios in Greece.

In the current era of sustainable development, inclusion of multiple factors as disagreeing goals, objectives, criteria, and stakeholders have led energy planning to transfer from single objective system to a more complex one (Mateo, 2012). Recently, sufficient energy planning that takes into account economic, environmental, social, political, and risk issues is the key to meet the growing demand for energy and to keep a system with a vision of sustainability. MCDM is one of the most efficient tools for energy planning as it helps decision makers to overcome socio- economic, environmental, institutional, technical issues involved in energy system design (Mateo, 2012).

MCDA approaches have wide applications in different fields including immigration, transport, environment, defense, education, health care, agriculture resource management etc.(Diaby, Campbell, & Goeree, 2013; Dodgson et al., 2009; Gregory et al., 2012; Hayashi, 2000; Thokala et al., 2016). In recent decades, popularity of MCDM has increased in the field of energy planning since it enables energy planners to give interest to all options are available and make correct decisions based on priority.

Numerous algorithms available to appraise and plan energy systems as per optimization of either single or multiple criteria (El-Khattam, Hegazy, & Salama, 2005; Gill, Kockar, & Ault, 2013; Keane et al., 2012; Kumar et al., 2014; Kumar et al., 2015; Schäfer & Moser, 2012; Yang & Nehorai, 2014).

Chapter Three

Research Methodology

3.1 Chapter Overview

This chapter presents the methodology that was applied in this study to select the best mix of RE alternatives in Palestinian Territories as described in the following sections.

3.2 Evaluating RE Technologies in Palestinian Territories

This study tracks six steps procedure to achieve its goal as shown in Figure (3.1). Process steps are summarized as:

- Defining research problems, and setting goals to handle the problem;
- Determining RE potential and opportunities in Palestinian Territories;
- Selecting the appropriate MCDM techniques to address the problem;
- Establishing criteria and subcriteria;
- Collecting the relevant data for generating the relevant matrices and to establish the weights of each alternative, criteria and subcriteria by using simple surveys and direct interviews with academics, regulators, and firms from RE sectors;
- Proceeding in the AHP;

- Using expert choice software to analyze the data from experts judgment, calculate consistency ratios (CR's) for matrices resulted from paired comparisons, and to perform the sensitivity analysis;
- Setting results and recommendations.

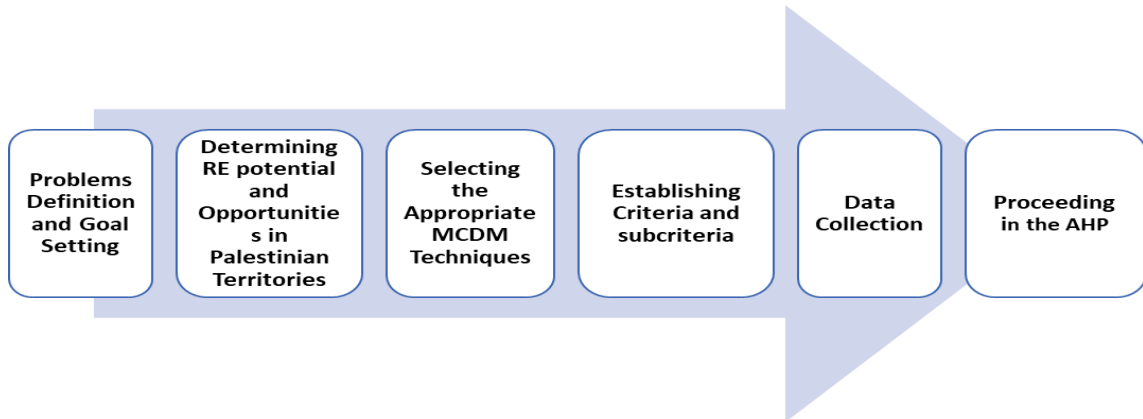


Figure (3.1): Proposed approach to rank renewable energy technologies for Palestinian Territories using analytical hierarchy process.

3.3 Problems Definition and Goal Setting

This study proposes a framework to evaluate each RE alternative that will be used in the mix of energy sources in Palestinian Territories. This country relies heavily on the imports for energy generation, but it has all the potential to invest in RE sector. Thus, a detailed analysis is needed to prioritize alternatives and RE portfolio.

3.4 Generating Alternatives

Based on the previous literature and Palestinian energy strategy, the proposed RE technologies are: solar PV, CSP, SWH, wind energy, geothermal energy, biomass, biogas, and WTE.

3.5 Selecting the Appropriate Model

AHP is one of MCDM techniques that is preferred by many users as it is simple, flexible, adaptable, does not involve complex mathematics, and since it is based upon hierarchal structure and thus each criterion and sub criterion can be better focused (Ishizaka & Labib, 2009; Shahroodi et al., 2012). This method has been proposed by Thomas Saaty in the 1970s (Shahroodi et al., 2012). AHP provides a framework that is capable to deal with differences and conflicts and to support decision making in the process of energy planning with RE's. Applying AHP in decision- making process follows a structural process, which can be summarized in the following steps:

Step one: Defining objective into a hierarchal model. In this technique the goal of the study is located at the top level of the hierarchy, whereas the solution alternatives are located at the bottom level. Criteria and subcriteria lie at the second and third level, respectively (Saaty and Vargas, 2012). Criteria and subcriteria are attributes that enable decision makers to set preferences and thus make the final decision. Many levels can be added by the decision maker based on the level of the analysis required.

Step two: The parameters of each level in the decision hierarchy are rated with respect to its parent node using nine- integer value scale proposed by Saaty (Saaty & Vargas, 2012). This scale is presented in Table (3.1) to rate the intensity of importance between parameter 1 and 2 with respect to its immediate upper level. Pairwise comparison matrix is formulated after all

parameters have been compared with preference scale pair by pair based on the decision makers' opinion.

Step three: Estimating weights of parameters on each level in the decision hierarchy after the judgment matrix is formulated. Eigen vectors, or it named relative weights, can be calculated by normalizing each column in the matrix; then, by summing up each row to obtain a row sum; after that, averaging each row in the matrix.

Table (3.1): AHP measurement scale.

Intensity of importance	Definition
1	Activity A is equally important to activity B
3	Activity A is slightly more important than activity B
5	Activity A is strongly more important than activity B
7	Activity A is very strongly more important than activity B
9	Activity A is extremely more important than activity B
2, 4, 6, 8	Intermediate values to comprise between weights values
Reciprocals	If activity A has one of the above non- zero numbers assigned to it when compared with activity B, then B has the reciprocal value when compared with A.

Source: (Saaty & Vargas, 2012).

Once the relative weights of alternatives have been calculated with respect to each sub criterion, the relative weights of each alternative due to each criterion can be obtained by multiplying the matrix resulted from the previous step by the local weights of subcriteria with respect to each criterion. This is depicted in Equation (3.1).

(Relative weights of alternatives with respect to each subcriterion)

* (Relative weights of subcriteria with respect to each criterion)

= (Relative weights of alternatives with respect to each criterion)

Equation (3.1)

Finally, the global weights of alternatives can be calculated by multiplying the weights of alternatives with respect to criteria by the relative weights of criteria with respect to goal. This is illustrated in Equation (3.2). The corresponding calculations will be shown in details in results and discussion chapter.

(Relative weight of alternatives with respect to each criterion) *

(Relative weight of criteria with respect to goal) =

(Alternatives weights)

Equation (3.2)

Step four: Validating the results by calculating the degree of consistency. The most important advantage of AHP is its ability to calculate consistency since people are inconsistent in their judgments. Consistency Ratio (CR) is used to measure consistency which is mathematically defined as

$$CR = \frac{CI}{RI} \quad \text{Equation (3.3)}$$

In which CI is the consistency index, which equals

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \text{Equation (3.4)}$$

Where λ_{max} is the largest eigenvalue and it is called the principle eigenvalue. RI is the random consistency index and it is defined as an average of the CIs of a large set of matrices with random inputs, and it

changes with respect to the number of parameters in a comparison (n). RI values with respect to n are illustrated in Table (3.2) (Saaty & Vargas, 2012).

Table (3.2): Random consistency index (RI).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Source: (Saaty & Vargas, 2012)

Step five: The last step in AHP is to calculate the overall weight of each criterion, sub criterion, and lastly RE technologies. The results of local and global weights are illustrated in results and discussion section.

According to Saaty (1977), weights are considered consistent if their CR is less than or equal to 10%, otherwise the data are inconsistent and the answers of the decision maker must be reviewed.

AHP method has been applied in different areas, including: resource management, corporate policy and strategy, energy planning, logistics, public policy, and transportation engineering (Ishizaka & Labib, 2009; Shahroodi et al., 2012). Relevance of this method in energy planning projects regarding RE's can be demonstrated in several studies. In Robles Algarín, Llanos, & Castro (2017), AHP method was used to assess RE's for rural areas in the Caribbean region of Colombia; Ahmad & Tahar (2014) adopted AHP for ranking RE sources in Malaysia. In 2016, Al Garni et al. applied AHP for evaluating renewable power generation sources in Saudi Arabia. In (Kablan, 2004), AHP was utilized for energy conservation policy selection process in Jordan. In 2009, Chatzimouratidis

& Pilavachi have used AHP to compare various power plants for electricity generation from technological and economic perspectives. Furthermore, AHP was used by Theodorou, Florides, & Tassou (2010) to find a suitable financing scheme for RE projects in Cyprus. Finally, sustainable electricity generation for Pakistan was evaluated in 2011 by Amer & Daim.

3.6 Selection of Criteria and Subcriteria

RE technologies prioritization for sustainable development is a complex mission since many parameters are overlapped in this task. Many factors must be considered in energy planning. Technical and economic factors have been and will continue to be critical in energy planning. The social factor has gained importance over years, so that neglecting this factor leads to fail in planning. Environmental, risk and political factors also play a key role in prioritizing renewable alternatives and should be taken into account to ensure proper planning. Hence, in this study, multi-perspective analysis approach is applied for ensuring a steady electricity supply and to reduce dependence on external resources for energy supply.

Reviewing literature reveals that most of studies in the field of energy planning utilize traditional evaluation methods, such as techno-economic or cost- benefit analysis assessment. As illustrated in Table (3.3), two or three aspects are applied to select the best renewable technology from year 2004 to 2021.

A comprehensive review of literature related to energy planning problems using multi- criteria decision tools was assessed to set the most common criteria and subcriteria. Preliminary list of 51 subcriteria was set, grouped into 5 categories: technical, economic, socio- political, environmental and risk. To establish the final subcriteria, three steps have been followed: first, omitting non- influential subcriteria for evaluating RE technologies in Palestinian Territories. Second, using subcriteria that are used by the majority of the researchers in the reviewed papers. Lastly, experts in the energy field reviewed the resulted list of criteria and subcriteria, and they added/ omitted subcriteria that is suitable for the Palestinian context. The most common criteria and subcriteria applied in the literature for appraising RE source are presented in Annex Tables (1 -5). Applying these steps resulted in 22 subcriteria grouped into five groups as illustrated in Table (3.4).

AHP model for this study is illustrated in Figure (3.2). This model consists of four levels comprising of goal, criteria, subcriteria and alternatives. The goal of the decision model is selection, appraising and prioritizing of RE technologies for sustainable development in Palestinian Territories.

Table (3.3): Utilization of multi- criteria for evaluation and prioritization of sustainable energy technologies.

Publication year	Criteria used in energy planning							References
	Technical	Economic	Environmental	social	Political	Risk	Flexible	
2004	x	x						(Aras, Erdoğmuş, & Koç, 2004)
2004	x	x	x					(Nigim, Munier, & Green, 2004)
2007			x	x				(Chatzimouratidis & Pilavachi, 2007)
2007	x	x	x					(Diakoulaki et al., 2007)
2007		x	x	x				(Nava & Daim, 2007)
2008		x						(Jaber, Jaber, Sawalha, & Mohsen, 2008)
2008	x	x						(Lee et al., 2008b)
2008	x			x	x			(Stephens, Wilson, & Peterson, 2008)
2009	x		x		x			(Chen, Oliver, Hsu, Hsu, & Sung, 2009)
2009		x	x					(Pilavachi, Chatzipanagi, & Spyropoulou, 2009)
2009	x	x						(Daim, Yates, Peng, & Jimenez, 2009)
2010	x	x						(Lee & Hwang, 2010)
2011	x	x	x	x	x			(Amer & Daim, 2011a)
2014	x	x	x	x				(Ahmad & Tahar, 2014)
2016	x	x	x	x	x			(Al Garni et al., 2016)
2017	x	x	x	x		x		(Algarín et al., 2017)
2018	x	x	x	x				(Lee & Chang, 2018)
2018	x	x	x					(Ishfaq, Ali, & Ali, 2018)
2021	x	x	x	x	x		x	(Saraswat & Digalwar, 2021)
2021	x	x	x	x	x	x		This research

Table (3.4): Selected subcriteria.

Criteria	Subcriteria
C1. Technical	SC ₁₁ Efficiency
	SC ₁₂ Technology maturity
	SC ₁₃ Resource availability
	SC ₁₄ Safety of energy system
	SC ₁₅ Infrastructure
	SC ₁₆ Reliability
	SC ₁₇ Complexity
C2. Economic	SC ₂₁ Capital cost
	SC ₂₂ Operational and maintenance cost (O&M)
	SC ₂₃ National economic development
	SC ₂₄ Payback period
	SC ₂₅ Levelized cost of energy (LCOE)
C3. Socio-political	SC ₃₁ Acceptability of local residents
	SC ₃₂ Employment creation
	SC ₃₃ National energy security/energy independency
C4. Environmental	SC ₄₁ CO2 emissions
	SC ₄₂ Requirement of land and water resources
	SC ₄₃ Visual impact
C5. Risk	SC ₅₁ Armed conflict
	SC ₅₂ Investment risk
	SC ₅₃ Land political categorization (A, B, C)
	SC ₅₄ Local legal framework maturity

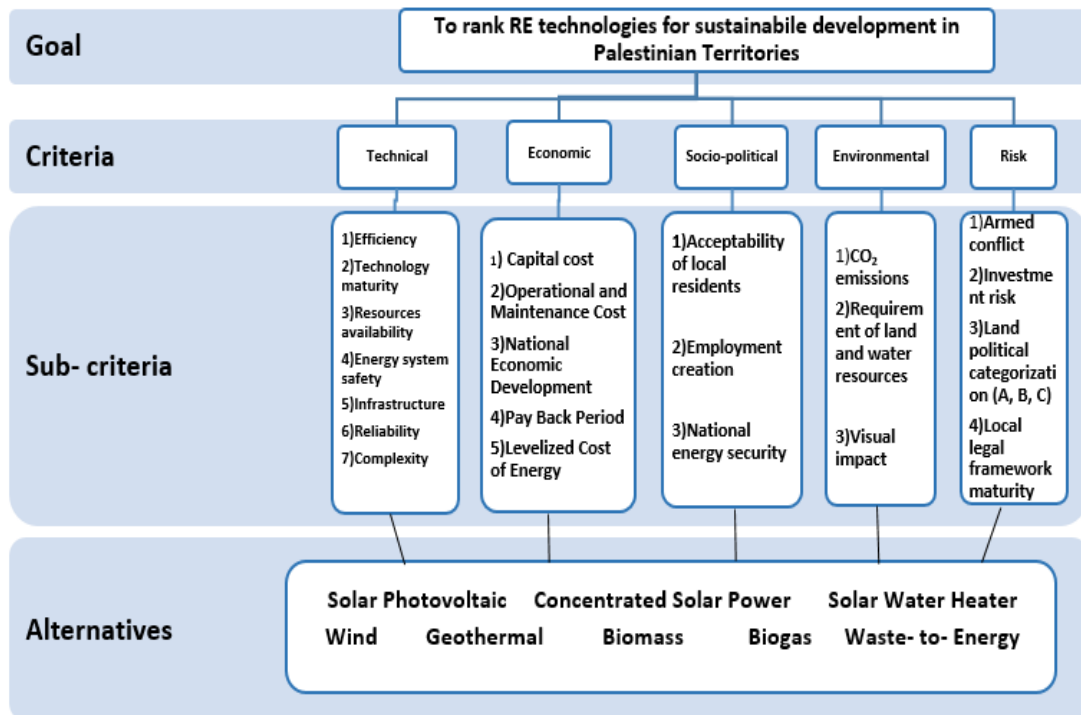


Figure (3.2): The proposed AHP model.

Detailed definitions and the data acquired for each sub criterion applied in this model are presented in the following subsections.

3.6.1 Technical Criteria (C1)

In this section, the technical relevance of the RE technologies are specified due to the scope established in the following subcriteria:

- 1. Efficiency (SC₁₁):** The efficiency parameter that measures how much energy can be acquired from the conversion of primary energy into electrical energy. It indicates a peak level of performance that utilizes the least amount of inputs to produce the highest amount of outputs. Annual energy report of the International Renewable Energy Agency (IRENA) was used to assess the efficiency percentage of different RE alternatives from year 2010 to the year 2020 (International Renewable Energy Agency (IRENA), 2021) while the efficiencies of SWH and WTE were acquired through experts' judgments. Table (3.5) presents a comparison of efficiency for the RE technologies.
- 2. Technology maturity (SC₁₂):** This criterion depicts a technology that has been in use for a long period of time in real world applications to overcome or reduce its inherent difficulties and initial faults through further development. A technology is considered mature if its significant background is well understood, and if it is being widespread internationally, locally, and being available commercially. Müller & Brown (2011) and IEA (2006) rated the different alternate technologies maturity perspective.

In literature, solar PV and SWH were rated as a second generation technologies, they have moderate maturity. But, In Palestinian Territories, SWH and solar PV were considered as very high mature technologies since they are in use for a long period of time. A comparison of the maturity of the technologies is introduced in Table (3.5) while the maturity' scale rating is presented in Table (3.9).

3. Availability (SC₁₃): This parameter reflects an access for each RE technology in order to generate electrical energy. It depicts the amount of time that it is able to generate electricity over a specific period, divided by the amount of time in the period. A power generation plant can be out of service due to weather conditions such as the lack of wind or sunlight or due to the repairs or maintenance of the system. Here we assume that there is no storage system except for thermal ones. Design of the factory and how the factory is operated, type of fuel, quality of tools, equipment, and its maintenance greatly affect its availability. Systems such as wind, photovoltaic and hydro power have low availability ranging between 20% and 60 %, whereas steam- electric systems such as biomass, biogas, natural gas and geothermal have higher availability ranging between 80% and 96%. Chatzimouratidis & Pilavachi (2009) have discussed the availability of solar PV, wind, geothermal, and biomass. Many references were used to determine the availability of other RE technologies (Chludziński & Duda, 2018; Energy Saver, n.d.; Funk, Milford, & Simpkins, 2013; International

Renewable Energy Agency (IRENA), 2012; Office of Nuclear Energy (NE), 2020). Table (3.5) shows the availability for each RE system.

- 4. Safety of energy system (SC₁₄):** Energy system safety indicates to which degree a specified RE source is safe and it does not result in a loss of human lives. This criterion is measured quantitatively through the number of fatal accidents at power factories over specific time periods. Expert judgments in addition to many studies have been used as an input to assess different RE sources like (Al Garni et al., 2016; Burgherr & Hirschberg, 2014; Burgherr, Hirschberg, & Spada, 2013). In these studies Energy- related Severe Accident Database (ENSAD), probabilistic safety assessment (PSA) in addition to the integration of available data, modeling, and expert opinions have been applied to provide a broad comparison of energy technologies. Table (3.5) rates different technologies based on the number of fatalities per GW year whereas Table (3.9) explains the scale used for ratings the safety of energy system.
- 5. Infrastructure (SC₁₅):** This criterion is considered as a qualitative parameter that means an existence of physical tools and instruments for the execution of energy system.
- 6. Reliability (SC₁₆):** Ability of the energy system to deliver an expected services. Reliable energy system has enough network capacity, demand response to supply customers with the needed energy at high level of confidence. This criterion also evaluates RE technologies if they have

been tested in a pilot factories, or it can be improved, or it is a familiar technology. IEA developed a scale divided into six categories to evaluate different energy alternatives from a reliability perspective as exposed in Table (3.11) (International Energy Agency (IEA), 2020). Consequently, assessment of RE technologies based upon expert judgments and IEA' report is depicted in Table (3.5). Expert judgments were used to assess the reliability of SWH, biomass, biogas, and WTE.

7. Complexity (SC₁₇): Complexity of RE technology relates to the period of construction and installation of the power generation plant. As illustrated in Table (3.5), complexity of energy system have been assessed with respect to expert choices and to the publisher Baris & Kucukali (2012). Decision makers assessed CSP, SWH, biogas, and WTE. Complexity of energy system have been sub- divided and rated into 3 categories as shown in Table (3.10).

3.6.2 Economic Criteria (C2)

With the economic criteria, the goal is to incorporate the cost and benefits incurred in excitation of the RE project, relating to the following subcriteria:

1. Investment cost (SC₂₁): It is one of the most common economic criterion to evaluate RE technologies. This criterion impacts the viability of the energy project. Investment cost is the expenses required to set up a power plant, including the cost of infrastructure, land, tools and equipment, installations, wages, engineering services, and

connecting the project with the national web. The data of this quantitative parameter were obtained from the energy report of the US Energy Information Administration (EIA) (U.S Energy Information Administration (EIA), 2020) and by using an article referred to Tayeh et al., (2021), as well as expert inputs for SWH. Table (3.6) compares investment cost among the considered alternatives.

- 2. Operational and Maintenance Cost (O&M) (SC₂₂):** O&M contains duties, functions, responsibilities, and labor related with daily production, replacement of components, repairs, and other activities needed to keep the system in safe and to maintain an acceptable services. A comparison of the operational and maintenance cost for the RE technologies is accomplished through an EIA report (U.S Energy Information Administration (EIA), 2020) and by this article (Tayeh et al., 2021) for WTE while the operational and maintenance cost of SWH was obtained through an expert judgments. A comparison of alternatives is shown in Table (3.6).
- 3. National Economic Development (SC₂₃):** A significant advantage of some RE technologies is that they improve the quality of life of nations, local community, region, and they also promote healthy economic status. National economic development is considered as qualitative factor, so comparison matrix will be built upon experts' judgments.

- 4. Pay Back Period (PBP) (SC₂₄):** PBP is a quantitative parameter that refers to the time required to recover the cost of the initial investment. Since there is a lack of studies considering PBP of the alternatives under study, qualitative assessment have been carried out through expert responses about the required payback period for different alternatives except for the PBP for WTE technology (Tayeh et al., 2021). A comparison of alternatives in terms of payback period is shown in Table (3.6).
- 5. Levelized Cost of Energy (LCOE) (SC₂₅):** It also named levelized cost of electricity. According to EIA (2020), LOCE refers to the “average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle”. The LCOE data of alternatives is obtained through an annual report affiliated to IRENA (2021), and through an article related to Tayeh et al. (2021) whereas the LCOE was obtained through experts opinions for SWH as depicted in Table (3.6).

3.6.3 Socio- political Criteria (C3)

These criteria allow for incorporation of the problems and benefits endured in execution a RE project in the communities of the Palestinian Territories, due to the scope established in the following subcriteria:

- 1. Acceptability of local residents (SC₃₁):** This parameter reflects the acceptance of the RE project by politicians and communities and their willingness to execute the project. The comparison of RE alternatives

from social acceptance perspective is discussed in (Achillas et al., 2011; Amer & Daim, 2011b; Baris & Kucukali, 2012; Paolini et al., 2018), and displayed in Table (3.7). SWH was appraised by experts. The scale was used for rating RE technologies is presented in Table (3.10).

- 2. Employment creation (SC₃₂):** Employment creation indicates the number of potential job created by an energy projects. These jobs include operations, maintenance and repair, and installation of the RE system. Employment opportunities are considered by government in the decision making process to assess their contributions. The employment creation data of each alternative is gained from IRENA jobs database (International Renewable Energy Agency (IRENA), 2020) except for SWH that was determined based on experts opinions. Table (3.7) illustrates the number of jobs in the energy sector for year 2019.
- 3. National energy security/energy independence (SC₃₃):** This qualitative factor can be enhanced by exploiting local energy sources, and reduce dependence on imported energy resources. Better energy source is the one that make a country less independent on the external energy sources.

3.6.4 Environmental Criteria (C4)

Environmental criteria concern the impact of the implementation of the RE project on the environment in terms of the following subcriteria:

- 1. CO₂ emission (SC₄₁):** It is a quantitative parameter that takes into account emissions of CO₂ gas generated by implementing RE system. Data are obtained from an EIA report to estimate cost and performance for new utility- scale electric power generating technologies (U.S Energy Information Administration (EIA), 2020) as well as expert responses for SWH, and based on Tayeh et al. (2021) for WTE. Table (3.8) shows a comparison of CO₂ emissions for RE technologies.
- 2. Requirement of land and water resources (SC₄₂):** It relates to the required water and land to implement an energy project. Land occupation differs from one energy technology to another for the same capacity. So, this parameter should be considered by decision makers. Troldborg et al (2014) rated RE alternatives whereas SWH were rated based upon expert views. Table (3.8) compares land and water requirements among the considered alternatives.
- 3. Visual impact (SC₄₃):** It is a qualitative parameter that reflects the impact of the energy plant on the surroundings.

3.6.5 Risk Criteria (C5)

Risk criteria aims to identify the expected and unforeseen risks that would significantly affect the performance of the energy system. These risks are measured qualitatively, and include:

1. **Armed conflict (SC₅₁):** Risks to which the energy system is exposed to events related to the armed conflict in the Palestinian Territories.
2. **Investment risk (SC₅₂):** Risks related to the variation in the market representative rate.
3. **Land political categorization (A, B, C) (SC₅₃):** This risk is due to the division of the West Bank according to the Oslo Accords into three areas A, B, and C where area C indicates full Israeli civilian and military control. About 60% of the land in West Bank exist in area C. Israeli practices and policies in settling, controlling, occupying and controlling West Bank lands impede the development of energy- related infrastructure and regulations.
4. **Local legal framework maturity (SC₅₄):** A clear and comprehensive energy policy for energy efficiency and for development of RE technologies is still weak. This is because of weak institutional framework and continuous Israeli occupation. This criterion measures goals' convergence between the suggested technology and the government policy. It considers the tendency of institutional actors and the government's support.

Table (3.5): Quantitative data for technical subcriteria.

Renewable energy technologies	Energy Output	Efficiency (%) (2010-2020)	Technology maturity	Availability (%)	Safety of Energy System	Reliability	Complexity
Solar PV	Electrical	16.3	Very high maturity (6)	20- 24.5	Lowest mortality (5)	Early adoption phase (5)	Less than 1 year (1)
CSP	Electrical	35.64	Least mature (1)	20-50	Low mortality (4)	Early adoption phase (5)	Less than 1 year (1)
SWH (evacuated tube)	Thermal	35	Very High maturity (6)	50-75	Low mortality (4)	Mature technology phase (6)	Less than 1 year (1)
Wind	Electrical	30.64	High maturity (5)	34.8- 38	Moderate mortality (3)	Early adoption phase (5)	Less than 1 year (1)
Geothermal	Thermal	83.8	Very high maturity (6)	95	Moderate mortality (3)	Mature technology phase (6)	Between 1 and 2 years(2)
Biomass	Thermal	77.7	Most mature (7)	80	Highest mortality (1)	Early adoption phase (5)	Between 1 and 2 years (2)
Biogas	Electrical	55.8	High maturity (5)	≥ 90	Highest mortality (1)	Early adoption phase (5)	Between 1 and 2 years (2)
WTE	Electrical	20- 25	High maturity (5)	≥ 91	Highest mortality (1)	Early adoption phase (5)	More than 2 years (3)

Source: Efficiency (International Renewable Energy Agency (IRENA), 2021), technology maturity (International Energy Agency (IEA), 2006; Müller & Brown, 2011), availability (Chatzimouratidis & Pilavachi, 2009; Chludziński & Duda, 2018; Energy Saver, n.d.; Funk et al., 2013; International Renewable Energy Agency (IRENA), 2012; Office of Nuclear Energy (NE), 2020), safety of energy system (Al Garni et al., 2016; Burgherr & Hirschberg, 2014; Burgherr et al., 2013), reliability (International Energy Agency (IEA), 2020), and complexity (Baris & Kucukali, 2012).

Table (3.6): Quantitative data for economic subcriteria.

Renewable energy technologies	Energy Output	Capital Cost (\$/KW)	Operational and Maintenance Cost (\$/KW-year)	Pay Back Period (years)	Levelized Cost of Energy (\$/KWh)(2020)
Solar PV	Electrical	1313	15.25	3-4	0.057
CSP	Electrical	7221	85.4	8-14	0.11
SWH (evacuated tube)	Thermal	1000	15.25	4-6	0.0127
Wind	Electrical	1265	26.34	4-8	0.039
Geothermal	Thermal	2521	128.544	6-12	0.071
Biomass	Thermal	4097	125.72	6-10	0.066
Biogas	Electrical	1563	20.1	6-10	0.066
WTE	Electrical	4672	82	≥8.5	0.05

Source: Capital cost (Tayeh et al., 2021; U.S Energy Information Administration (EIA), 2020), operational and maintenance cost (Tayeh et al., 2021; U.S Energy Information Administration (EIA), 2020), Pay Back Period (Tayeh et al., 2021), and levelized cost of energy (International Renewable Energy Agency (IRENA), 2021; Tayeh et al., 2021).

Table (3.7): Quantitative data for socio- political subcriteria.

Renewable energy technologies	Energy Output	Employment creation (Total job-2019 year)	Acceptability of local residents (%)
Solar PV	Electrical	3755	2
CSP	Electrical	30	2
SWH (evacuated tube)	Thermal	5600	3
Wind	Electrical	1165	2
Geothermal	Thermal	99	2
Biomass	Thermal	764	3
Biogas	Electrical	342	2
WTE	Electrical	39	2

Source: Employment creation (International Renewable Energy Agency (IRENA), 2020), public acceptance (Achillas et al., 2011; Amer & Daim, 2011b; Baris & Kucukali, 2012; Paolini et al., 2018).

Table (3.8): Quantitative data for environmental subcriteria.

Renewable energy technologies	Energy Output	CO₂ Emissions (lb/MMBtu)	Land and water requirements (m² /kW)
Solar PV	Electrical	0	10
CSP	Electrical	0	10
SWH (evacuated tube)	Thermal	0	5
Wind	Electrical	0	200
Geothermal	Thermal	0	100
Biomass	Thermal	206	4000
Biogas	Electrical	117	4000
WTE	Electrical	67	25

Source: CO₂ emissions (Tayeh et al., 2021; U.S Energy Information Administration (EIA), 2020), and land and water requirements (Troldborg et al., 2014).

Table (3.9): Scale ratings of maturity and energy system safety.

CRITERIA	SCORE = 1	SCORE = 2	SCORE = 3	SCORE = 4
MATURITY	Least mature	Very low maturity	Low maturity	Moderate maturity
	SCORE = 5	SCORE = 6	SCORE = 7	
	High maturity	Very high maturity	Most mature	
SAFETY OF ENERGY SYSTEM	SCORE = 1	SCORE = 2	SCORE = 3	SCORE = 4
	Highest mortality	High mortality	Moderate mortality	Low mortality
	SCORE = 5	SCORE = 6	SCORE = 7	
	Lowest mortality	-	-	

Table (3.10): Evaluation matrix for the comparison of the electricity generation technologies.

CRITERIA	SCORE = 1	SCORE = 2	SCORE = 3
COMPLEXITY	Less than 1 year	Between 1 and 2 years	More than 2 years
ACCEPTABILITY OF LOCAL RESIDENTS	The power generation plant limits or prevents local community to utilize surrounding lands.	The power generation plant has visual pollution and important noise.	The power generation plant provides economic benefits to local communities.

Source: (Baris & Kucukali, 2012)

Table (3.11): Technology readiness level scale applied by IEA.

TECHNOLOGY READINESS LEVEL APPLIED BY THE IEA	DESCRIPTION	SCALE
CONCEPT LEVEL	Technology that have been formulated and it needs to be validated.	1
SMALL PROTOTYPE LEVEL	It is a technology that didn't have a clear design, and still its prototype needs to be validated in test conditions.	2
LARGE PROTOTYPE LEVEL	Prototype of a given technology is proved at scale in conditions to be deployed	3
DEMONSTRATION PHASE	Power generation technology is tested in real world environments	4
EARLY ADOPTION PHASE	In this level designs have clear concept, and it is validated at demonstration and prototype phase.	5
MATURE TECHNOLOGY PHASE	Technology that are close to reach the theoretical limits of efficiency. It is the technology that have reached sizable deployment and for which only incremental innovations are expected.	6

Source: (International Energy Agency (IEA), 2020).

Chapter Four

Prioritization

4.1 Chapter Overview

This chapter clarifies the procedure that was adopted in order to generate all the comparison matrices. Also, it explains the equations that were employed in the transformation process. Furthermore, it expresses examples of generating comparison matrices for quantitative data and for qualitative ones.

4.2 Prioritization Procedure

In AHP, subcriteria can be classified as tangible and intangible. Tangible data is the one that can be measured quantitatively through international databases, or the literature where similar projects have been applied as capital cost, efficiency, etc. On the other hand, intangible data is the one that cannot be measured quantitatively and thus it can be obtained objectively based on experts' judgments as national economic development.

For energy alternatives assessment, it is more preferable to use measurable data whenever possible over non-measurable ones. This in turns can reduce inconsistency problems resulting from opinions differences. Expert judgments are involved fully to assess the five criteria with respect to their goal, and subcriteria with respect to their parent node while for alternatives

prioritization, a combination of experts' inputs as well as quantitative data are needed to evaluate alternatives with respect to different subcriteria.

The questionnaire used in this study to collect relevant data comprises of sixteen parts ordered in a hierarchal manner. The first part explains the goal, scale description and the evaluation mechanism applied in this study. Also, it includes information about the participant who filled out the questionnaire. The next section enables experts to evaluate criteria against each other with respect to the goal. Then, from part three to part seven, experts can prioritize technical subcriteria, economic subcriteria, socio-political subcriteria, environmental subcriteria, and risk subcriteria. This in its turns provides the local weights of each subcriteria with respect to their parent node, as well global weights with respect to goal. Afterwards, from section eight to section fifteen, experts were asked to weight alternatives against subcriteria that lack data and cannot be measured quantitatively as armed conflict and visual impact. Finally, in the last part, experts feel free to add any criteria they see it is important or to remove any one they consider it not affecting the process of alternatives evaluation. This modification can be proceeded in the sensitivity analysis. The questionnaire used in this study attached as appendix A and appendix B.

In order to evaluate RE technologies by decision makers, a cross- sectional sample of 35 experts in each of the following categories were consulted and asked to fill a questionnaire as illustrated in Table (4.1).

Table (4.1): Sample categories.

Participants in the study	Sample size
Palestinian Energy and Natural Resources Authority	6
Palestinian Electricity Transmission Company	8
Electricity Distribution Company	5
Energy Research Center- An Najah National University	4
Academics	6
NGO's	2
Private Sector (People who work in private sector exclusively).	4
Total sample	35

After the process of data collection, experts' answers are aggregated and the geometric mean is calculated to generate the rank number of alternatives. Afterwards, the pairwise comparison of alternatives based on AHP scale is conducted according to Equation (4.3). Lastly, Expert Choice software is applied to generate local weights, global weights, CR's, and to perform sensitivity analysis. Flow chart of the prioritization process is expressed in Figure (4.1).

Rank number scaling method (RNA) can be used for qualitative and quantitative inputs. It facilitates the process of data aggregation through replacing direct classic pairwise comparison by evaluation on nine- level scale, and thus reducing the number of pairwise comparisons that are filled out by the participants between each of the two elements and increasing the accuracy of answers. This method can be applied according to the following equations:

1. Finding the step value (h):

$$h = \frac{O_{\max} - O_{\min}}{9} \quad \text{Equation (4.1)}$$

O_{\max} is the maximum value, whereas O_{\min} is the lowest value among all the compared alternatives.

2. Ranking number of alternative ($RNA_{(i)}$) by taking values from one to nine according to Saaty's numerical scale. $RNA_{(i)}$ is calculated and converted into an integer value as illustrated in Equation (4.2).

$$RNA_{(i)} = \begin{cases} \text{INT} \left(9 - \frac{O_i - O_{\min}}{h} \right), & \text{If } O_{\min} \text{ is the best} \\ \text{INT} \left(\frac{O_i - O_{\min}}{h} \right), & \text{If } O_{\max} \text{ is the best} \end{cases} \quad \text{Equation (4.2)}$$

O_{\min} is the minimum value among alternatives being checked, alternative with the lowest value gets the highest rank number. Whereas O_{\max} is the highest value, alternative with the highest value is considered the best and gets the highest value.

3. A pairwise comparison matrix between two alternatives (one and two) based on AHP numerical scale is obtained by applying scoring value equation ($SV_{1 \rightarrow 2}$) as illustrated in Equation (4.3).

$$SV_{1 \rightarrow 2} = \begin{cases} \frac{1}{(RNA(2) - RNA(1) + 1)}, & \text{If } RNA(1) - RNA(2) < 0 \\ (RNA(1) - RNA(2) + 1), & \text{If } RNA(1) - RNA(2) \geq 0 \end{cases} \quad \text{Equation (4.3)}$$

Table (4.2) illustrates the conversion into RNA for the LCOE, where alternatives with minimum values are preferred. Wind energy has the minimum LCOE ($O_{\min} = 0.053$) and gains the highest $RNA_{(i)} = 9$, whereas

CSP and SWH have the highest LCOE ($O_{\max} = 0.182$) and therefore they have the lowest $RNA_{(i)} = 1$.

Table (4.2): Rank number of alternatives for LCOE.

Renewable energy technologies	Levelized Cost of Energy (\$/KWh)	RNA
Solar PV	0.057	4
CSP	0.11	1
SWH	0.0127	9
Wind	0.039	6
Geothermal	0.071	3
Biomass	0.066	4
Biogas	0.066	4
WTE	0.05	5

Table (4.3) shows the pairwise comparison matrix of the investigated alternatives with respect to the LCOE according to Equation (4.3).

In qualitative cases as visual impact, experts evaluated each alternative based on a nine- level scale with respect to their parent node. Then, the geometric mean is calculated for all answers to generate $RNA_{(i)}$. Afterwards as in quantitative parameters analysis, pairwise comparison matrices are formulated according to Equation (4.3).

Table (4.4) shows the RNA for each criterion with respect to the goal. The geometric mean has been calculated then it rounded to an integer value to form the rank number of each criterion. Prioritization of criteria with respect to their goal is shown in Table (4.5).

After the process of data aggregation for both quantitative and qualitative data, 28 comparison matrices have been generated in this study. Comparison matrices for the remaining sub criteria and alternatives are presented in Annex Tables (6- 31).

Table (4.3): Pairwise comparison matrix of alternatives with respect to LCOE subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	4	0.1667	0.333	2	1	1	0.5
CSP	0.25	1	0.111	0.1667	0.333	0.25	0.25	0.2
SWH	6	9	1	4	7	6	6	5
Wind	3	6	0.25	1	4	3	3	2
Geothermal	0.5	3	0.143	0.25	1	0.5	0.5	0.333
Biomass	1	4	0.1667	0.333	2	1	1	0.5
Biogas	1	4	0.1667	0.333	2	1	1	0.5
WTE	2	5	0.2	0.5	3	2	2	1

Table (4.4): Rank number of each criterion with respect to goal.

Criteria	Geometric mean	RNA
Technical	7.97783555	7
Economic	7.731401248	7
Socio-political	5.51615529	5
Environmental	5.82831652	5
Risk	5.542470536	5

Table (4.5): Pairwise comparison matrix of criteria.

Criteria	Technical	Economic	Socio-political	Environmental	Risk
Technical	1	1	3	3	3
Economic	1	1	3	3	3
Socio-political	0.333	0.333	1	1	1
Environmental	0.333	0.333	1	1	1
Risk	0.333	0.333	1	1	1

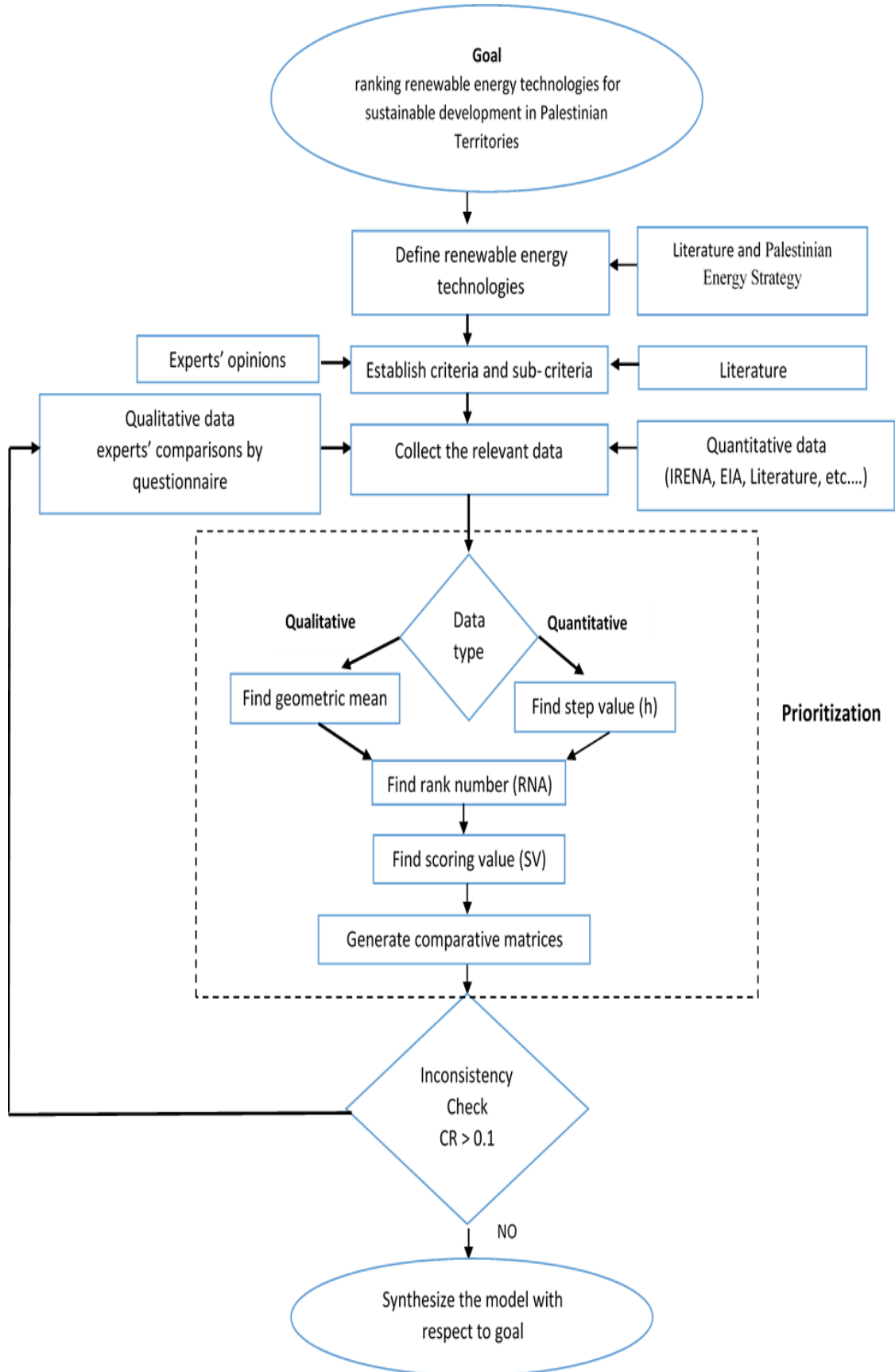


Figure (4.1): Prioritization approach for ranking renewable energy technologies in Palestinian Territories.

Chapter Five

Results and discussion

5.1 Chapter Overview

After the process of prioritization and by using Expert Choice, AHP model and all the comparison matrices have been established to set local and global preference for all levels of the hierarchal tree (e.g. criteria, subcriteria, and final selection alternatives) as shown in the following sections.

5.2 Results of Weights for Criteria

In this section, a pairwise comparison was conducted of each list of criteria with respect to their goal. Results revealed that technical and economic criteria come in the first place with a weight of 33.3% whereas the socio-political, risk and environmental come in second place; their relative weights are each 11.1%. CR for this comparison equals 0 which is acceptable. The results are shown in Figure (5.1).

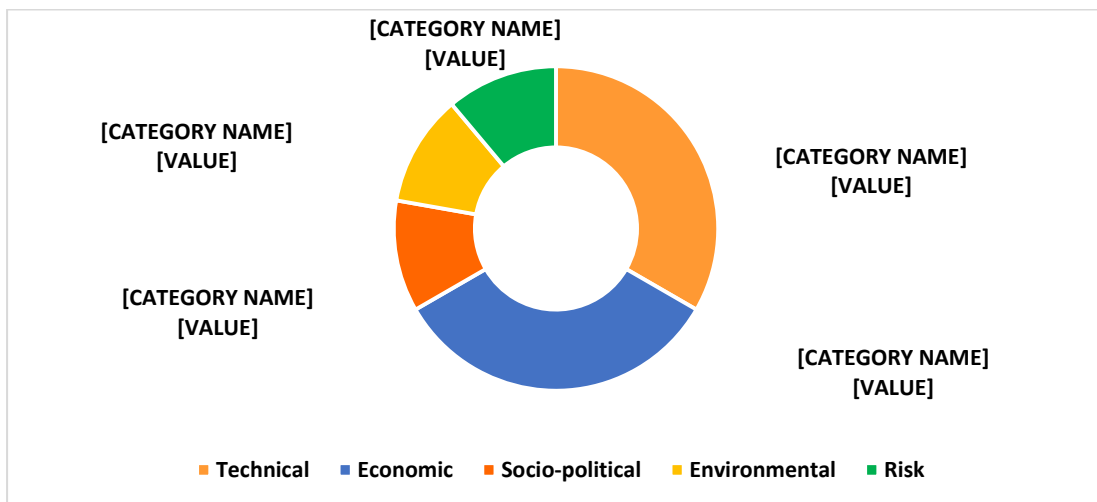


Figure (5.1): Priority weights of criteria with respect to goal.

Decision makers in Palestinian Territories give highest importance to the technical and financial aspects over others as environmental, social, political, risk, and environmental. This in turns explains why technical and economic criteria get the highest rankings in this research.

In the present work, criteria rankings are consistent with the results obtained in Al Garni et al. (2016), where four of the main criteria set in this research were used: technical, economic, socio- political, and environmental. In line with this research, technical and economic criteria get the first highest priority with respect to the goal; their relative weights are each 35.1%. However, unlike this research, socio- political and environmental score 18.9% and 10.9%, respectively.

The results obtained in this study can be compared with the research carried out by Algarín et al. (2017) for prioritizing RE sources for rural areas in the Caribbean region of Colombia. The criteria with the highest priority was technical (24.7%), followed by environmental (21.7%), social (19.6%), economic (17.9%) and risk (16.3%). In the work done by Rojas- Zerpa & Yusta (2014) for electric supply planning in rural remote areas, also, the first place of preference was for technical criteria (30.14%), then for social (26.65%), environmental (22.48%), and economic criteria (20.72%).

On the other hand, in Ahmad & Tahar (2014b), research was carried out to evaluate RE alternatives for sustainable development in Malaysia, in which, the highest weight was for economic criteria (52%), followed by technical (26%), environmental (15%) and social (7%). Economic criteria

also gets the highest weights with 35% in the work done by Amer & Daim (2011b), whereas, the weights of technical criteria, environmental, social and political were: 26%, 15%, 12%, 12%, respectively.

5.3 Results of Local and Global Weights for Subcriteria

Table (5.1) shows the local weights for each list of subcriteria with respect to their parent criteria. Results indicate that the most important technical subcriteria are efficiency, resource availability, safety of energy system, infrastructure and reliability with a local weight of 17.1%. For economic subcriteria, capital cost, PBP and LCOE get the highest weights with a weight of 25%.

In the case of socio- political subcriteria, the highest priority was for national energy security with a local weight of 50%, followed by acceptability of local residents and employment creation with a local weight of 25% for each of them. For environmental subcriteria, the first two places of importance were assigned to the CO₂ emissions and requirement of land and water resources with a local weight of 40% for each of them.

Land political categorization (A, B, C) under risk criterion has the highest importance with a local weight of 42.4% whereas the second place of relevance were for investment risk and local legal framework maturity, each with a relative weight of 22.7%. In the last place is armed conflict with a local weight of 12.2%. Each CR that resulted from the comparison of subcriteria with respect to their decision criterion were ranged from 0%

to 0.39% as shown in Table (5.1), which means that experts were consistent in their answers.

Table (5.1): Local weights of subcriteria with respect to each parent criterion.

Criteria	Subcriteria	Local weight (%)	CR (%)
C1. Technical	SC ₁₁ . Efficiency	17.1	0.105 %
	SC ₁₂ . Technology maturity	8.9	
	SC ₁₃ . Resource availability	17.1	
	SC ₁₄ . Safety of energy system	17.1	
	SC ₁₅ . Infrastructure	17.1	
	SC ₁₆ . Reliability	17.1	
	SC ₁₇ . Complexity	5.5	
C2. Economic	SC ₂₁ . Capital cost	25	0
	SC ₂₂ . Operational and maintenance cost (O&M)	12.5	
	SC ₂₃ . National economic development	12.5	
	SC ₂₄ . Payback period	25	
	SC ₂₅ . Levelized cost of energy	25	
C3. Socio-political	SC ₃₁ . Acceptability of local residents	25	0
	SC ₃₂ . Employment creation	25	
	SC ₃₃ . National energy security	50	
C4. Environmental	SC ₄₁ . CO2 emissions	40	0
	SC ₄₂ . Requirement of land and water resources	40	
	SC ₄₃ . Visual impact	20	
C5. Risk	SC ₅₁ . Armed conflict	12.2	0.39%
	SC ₅₂ . Investment risk	22.7	
	SC ₅₃ . Land political categorization (A, B, C)	42.4	
	SC ₅₄ . Local legal framework maturity	22.7	

In Figure (5.2), all of the subcriteria are displayed according to their global weights. It can be seen that capital cost, PBP and LCOE under economic criterion, each with a weight of 8.33%, have the highest influence on the

decision- making process. In contrast, visual impact under environmental criterion, complexity under technical criterion and armed conflict under risk criterion occupied the last three places of significance.

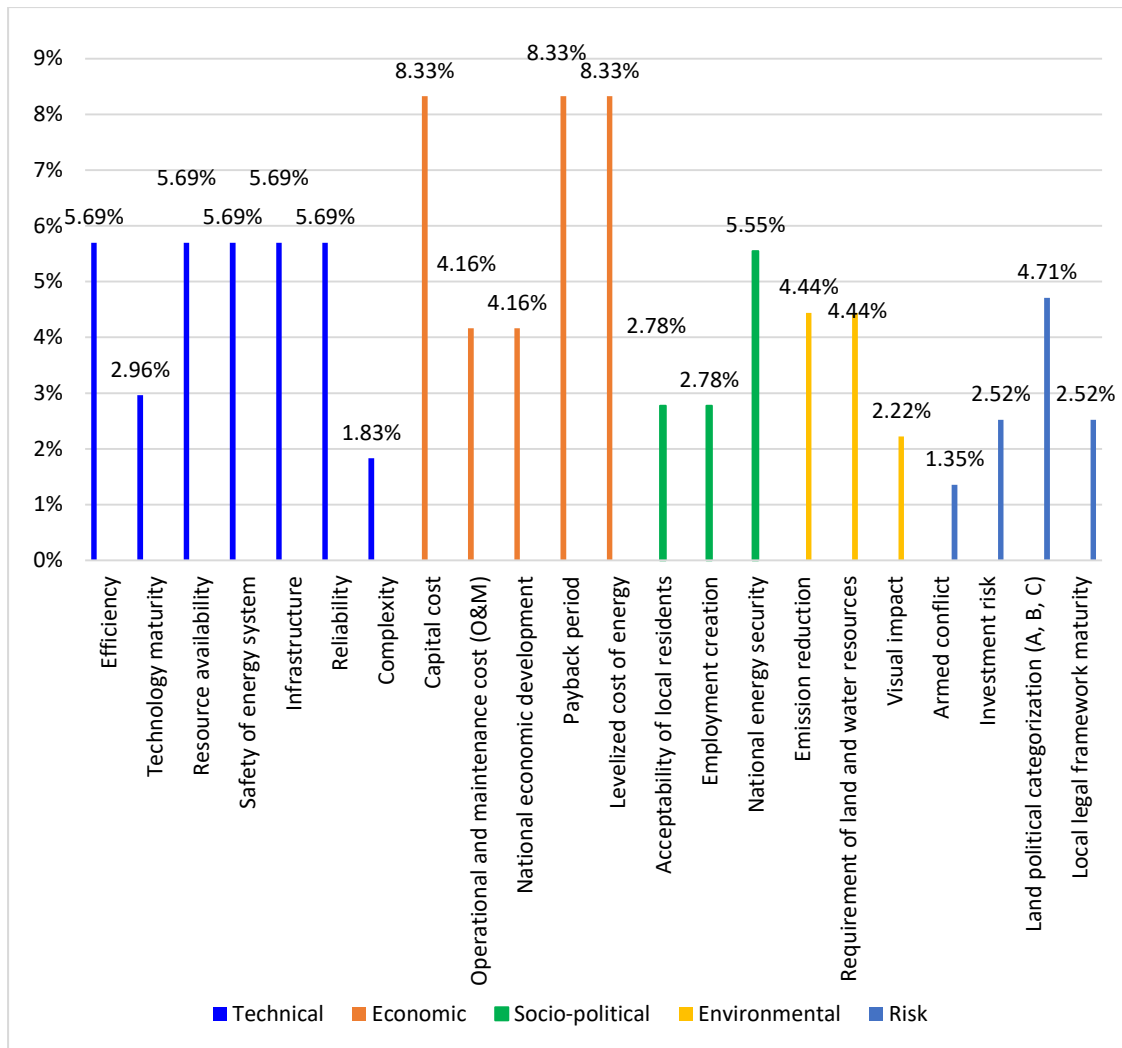


Figure (5.2): Global weights of subcriteria with respect to goal.

5.4 Results of Local and Global Weights for Alternatives

Here in this section, the eight RE technologies were compared through a hierarchy of four levels with respect to each studied sub criterion. These comparisons have depended on quantitative data for tangible subcriteria, and through decision makers' inputs for qualitative ones. As shown in

Tables (5.2- 5.6), these comparisons resulted in the local weights of the alternatives to each sub criterion. Score of RE alternatives toward the goal depends on the performance of each RE technologies in each sub criterion. All the CR's resulted from this step were considered consistent since they didn't exceed the limit of 10%.

Table (5.2): Local weights of alternatives with respect to each technical sub criterion.

Technical sub- criteria							
Alt.	Efficiency	Technology maturity	Resource availability	Safety of energy system	Infrastructure	Reliability	Complexity
Solar PV	0.029	0.139	0.023	0.418	0.292	0.042	0.215
CSP	0.048	0.018	0.023	0.17	0.084	0.042	0.215
SWH	0.048	0.139	0.062	0.17	0.292	0.375	0.215
Wind	0.029	0.078	0.023	0.08	0.049	0.042	0.215
Geothermal	0.389	0.104	0.31	0.08	0.033	0.375	0.041
Biomass	0.292	0.326	0.143	0.027	0.084	0.042	0.041
Biogas	0.135	0.097	0.208	0.027	0.084	0.042	0.041
WTE	0.029	0.097	0.208	0.027	0.084	0.042	0.018
CR (%)	3	4	3	3	1	0	2

Table (5.3): Local weights of alternatives with respect to each economic sub criterion.

Economic sub- criteria					
Alt.	Capital cost	Operational and maintenance cost	National economic development	Payback period	Levelized cost of energy
Solar PV	0.18	0.264	0.398	0.4	0.071
CSP	0.018	0.041	0.078	0.024	0.023
SWH	0.283	0.264	0.138	0.223	0.426
Wind	0.18	0.174	0.045	0.16	0.178
Geothermal	0.085	0.021	0.045	0.034	0.044
Biomass	0.044	0.021	0.078	0.053	0.071
Biogas	0.18	0.174	0.078	0.053	0.071
WTE	0.031	0.041	0.138	0.053	0.117
CR (%)	3	3	0.936	3	2

Table (5.4): Local weights of alternatives with respect to each socio-political sub criterion.
















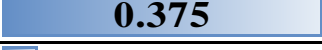








Socio-political sub- criteria			
Alt.	Acceptability of local residents	Employment creation	National energy security
Solar PV	 0.042	 0.246	 0.276
CSP	 0.042	 0.045	 0.094
SWH	 0.375	 0.483	 0.168
Wind	 0.042	 0.045	 0.053
Geothermal	 0.042	 0.045	 0.053
Biomass	 0.375	 0.045	 0.094
Biogas	 0.042	 0.045	 0.094
WTE	 0.042	 0.045	 0.168
CR (%)	0	0.97	0.501

Table (5.5): Local weights of alternatives with respect to each environmental sub criterion.

























Enviromental sub- criteria			
Alt.	CO2 emissions	Requirement of land and water resources	Visual impact
Solar PV	 0.179	 0.142	 0.297
CSP	 0.179	 0.142	 0.11
SWH	 0.179	 0.251	 0.192
Wind	 0.179	 0.142	 0.06
Geothermal	 0.179	 0.142	 0.06
Biomass	 0.016	 0.019	 0.06
Biogas	 0.027	 0.019	 0.11
WTE	 0.06	 0.142	 0.11
CR (%)	2	0.534	0.474

Table (5.6): Local weights of alternatives with respect to each risk sub criterion.

Risk sub- criteria				
Alt.	Armed conflict	Investment risk	Land political categorization (A, B, C)	Local legal frame work maturity
Solar PV	0,1	0.309	0.199	0.326
CSP	0,1	0.125	0.065	0.081
SWH	0.2	0.205	0.305	0.222
Wind	0,1	0.044	0.065	0.081
Geothermal	0,1	0.044	0.065	0.046
Biomass	0,1	0.073	0.119	0.081
Biogas	0,1	0.073	0.065	0.081
WTE	0.2	0.125	0.119	0.081
CR (%)	0	0.987	0.448	0.478

Relative weights of alternatives resulted from previous step formulate a matrix which can be multiplied by the local weights of subcriteria with respect to each criterion to get the relative weights of each alternative due to each criterion. This is depicted in Equation (3.1) in section titled: Selecting the Appropriate Model.

Figure (5.3) illustrates the performance of each alternative in each criterion. From technical aspect, it can be noticed that geothermal performed the best owing to its highest reliability, efficiency, and resource availability. In the case of economic criteria, SWH ranked top due to its lowest capital cost, operation and maintenance cost, and with respect to its lowest levelized cost of energy.

For the socio- political criteria, SWH also got the highest priority due to its ability to create more jobs, and due to its acceptability by people in Palestinian Territories. Compared to other alternatives, SWH obtained the

most relevance with environmental and risk criteria. This because it is the most alternative that is less effected by armed conflict and land political categorization. Also, it have the lowest requirements of land and water resources, and it is the alternative with low carbon emissions.

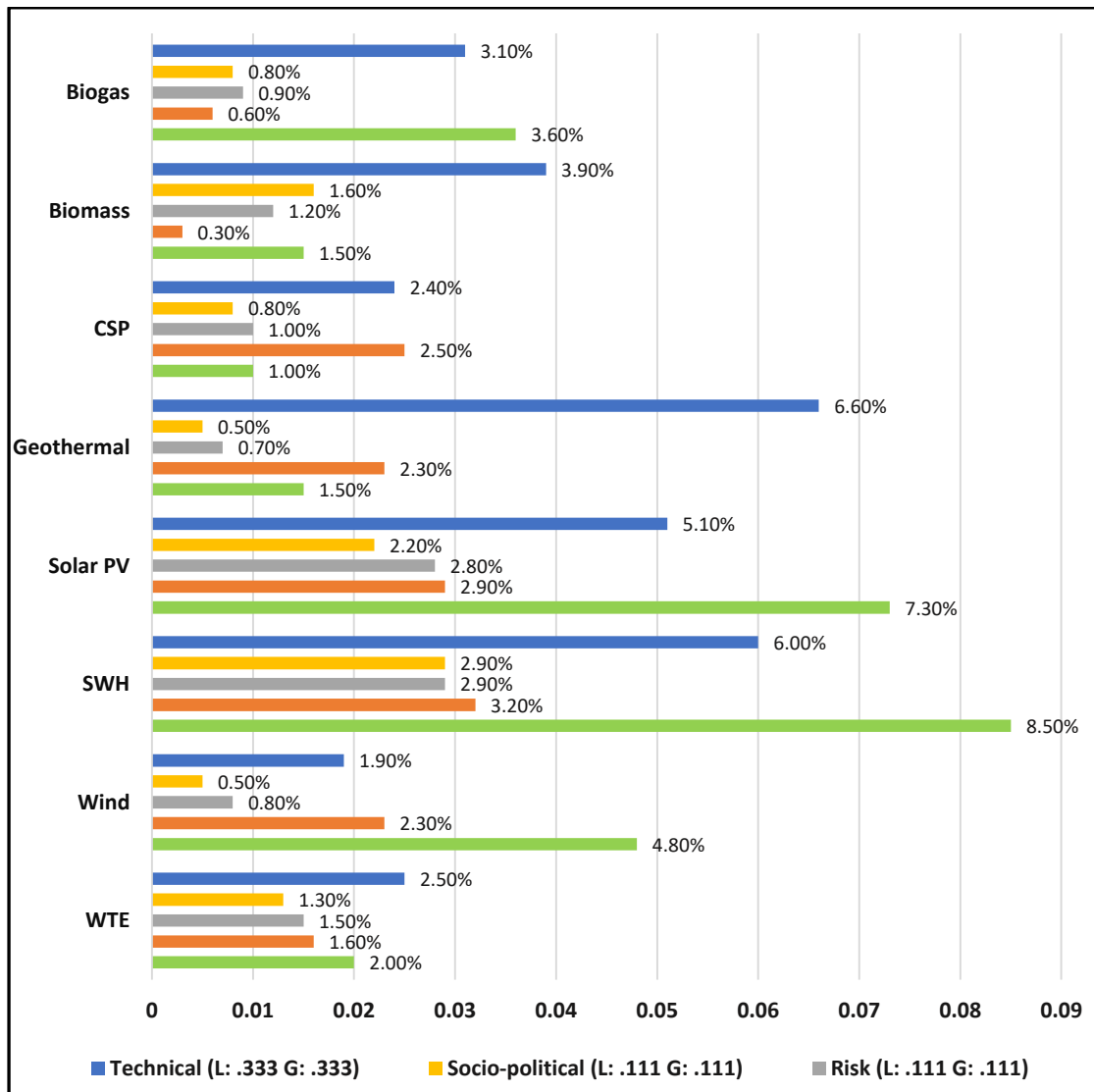


Figure (5.3): Local weights of alternatives under each decision criterion.

None of RE technologies performs equally well on all five decision criteria considered in this study. This is obvious in Figure (5.4). Geothermal seems to be a more technically viable option, while biomass scores the lowest on environmental criteria. Solar PV is inclined towards socio-political,

economic, risk and environmental criteria. Wind performs the worst on technical criteria. SWH scores more on all aspects except the technical one, whilst, CSP gets the lowest score on economic criteria.

Once all the relative weights of RE alternatives throughout the hierarchy were determined, global weights of alternatives can be obtained by aggregating the relative weights over different levels of the proposed model. Combined priority of all alternatives can be calculated, as in Equation (3.2) in section titled: Selecting the Appropriate Model , by multiplying the local weights of alternatives with respect to their parent criterion by the relative weight of criteria with respect to goal. Equation (5.1) explains the corresponding matrix calculations.

	Technical	Economic	Socio – political	Environmental	Risk
Solar PV	0.160	0.243	0.219	0.184	0.231
CSP	0.076	0.031	0.074	0.156	0.087
SWH	0.187	0.280	0.269	0.207	0.248
Wind	0.061	0.160	0.049	0.148	0.070
Geothermal	0.209	0.051	0.049	0.148	0.063
Biomass	0.127	0.051	0.148	0.024	0.098
Biogas	0.098	0.118	0.074	0.037	0.076
WTE	0.081	0.067	0.119	0.096	0.127

$$* \begin{bmatrix} \text{Criteria weights} \\ 0.333 \\ 0.333 \\ 0.111 \\ 0.111 \\ 0.111 \end{bmatrix} = \begin{bmatrix} \text{Alternatives weights} \\ 0.203 \\ 0.076 \\ 0.234 \\ 0.104 \\ 0.118 \\ 0.087 \\ 0.089 \\ 0.089 \end{bmatrix} \quad \text{Equation (5.1)}$$

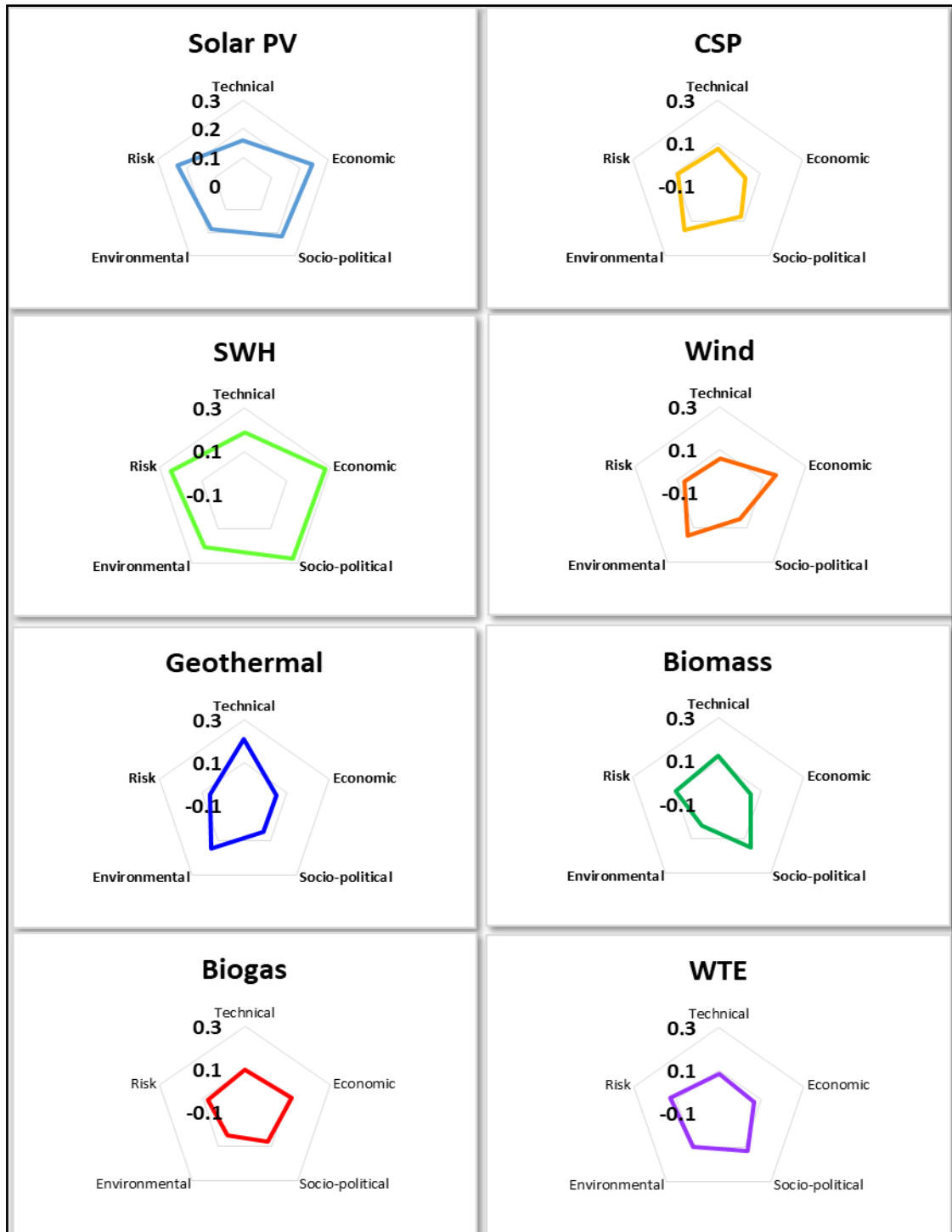


Figure (5.4): Performance of RE alternatives with respect to each criterion.

According to the assessment model developed in this study, SWH is the best promising RE technology to be adopted for sustainable development followed by solar PV, geothermal, wind, WTE, biogas, biomass, and lastly

CSP. The assessment of RE technologies in realizing the goal is presented in Figure (5.5). SWH outranks others technologies with a weight of 23.4% as it is has high infrastructure availability and reliability, low complexity, low O&M costs, the lowest LCOE and capital cost, and the lowest requirements of land and water resources. SWH is also less affected by land political categorization, and it presents an excellent performance with regard to armed conflicts, carbon emissions, and acceptability of local residents.

Solar PV comes in the second place with a weight of 20.3% on the basis of infrastructure potential, complexity, O&M costs, carbon emissions, lowest PBP and investment risk, highest contribution to the national energy independency and economic development. Solar PV also is the safest alternative, the most alternative that have a visual impact and the most legally mature technology to produce electricity.

Geothermal performed remarkably in technical criteria as it has the highest resource availability and efficiency, and high reliability. Besides, it has low carbon emissions, and low requirements of land and water resources. Geothermal comes in the third place with a weight of 11.8%.

Based on the relative weights of wind alternative in land and water resources requirement, complexity, carbon emissions, and O&M costs, wind has the fourth highest relative weight of 10.4%.

In the case of biogas and WTE energy, it can be noticed that their weights are each 8.9%. Biogas scores well with respect to resource availability and O&M costs, whilst, WTE energy has a low carbon emissions, low requirements of land and water resources, high resource potential and high national energy security . In the last two places of reference are biomass (8.7%), and CSP (7.6%) This is attributed to their modest performance on most criteria aspects compared to other technologies.

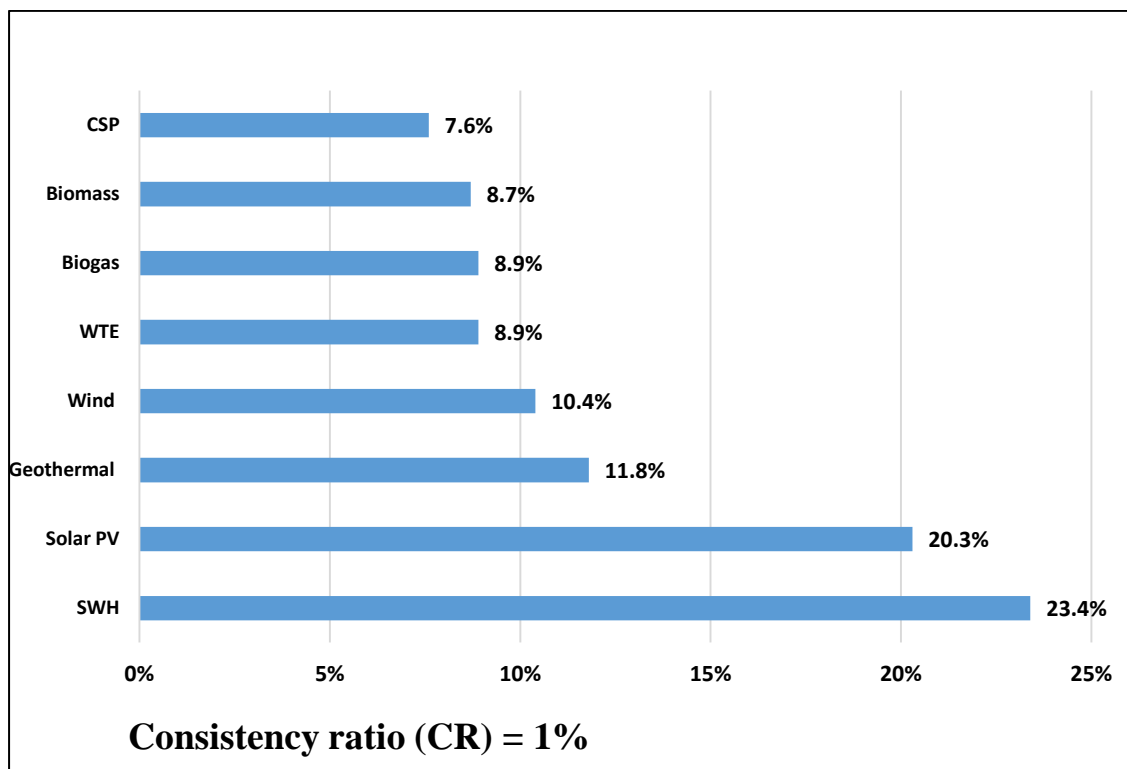


Figure (5.5): Global weights of alternatives with respect to goal.

Consistency ratio of the model equals to 1%, which means that answers' inconsistency is acceptable, and thus, subjective judgments should not be revised.

Figure (5.6) presents the global weights of RE alternatives that will be used to generate heat. SWH comes in the first place with a weight of 53.30%, then geothermal with a weight of 26.88%, and lastly biomass with a weight of 19.82%.

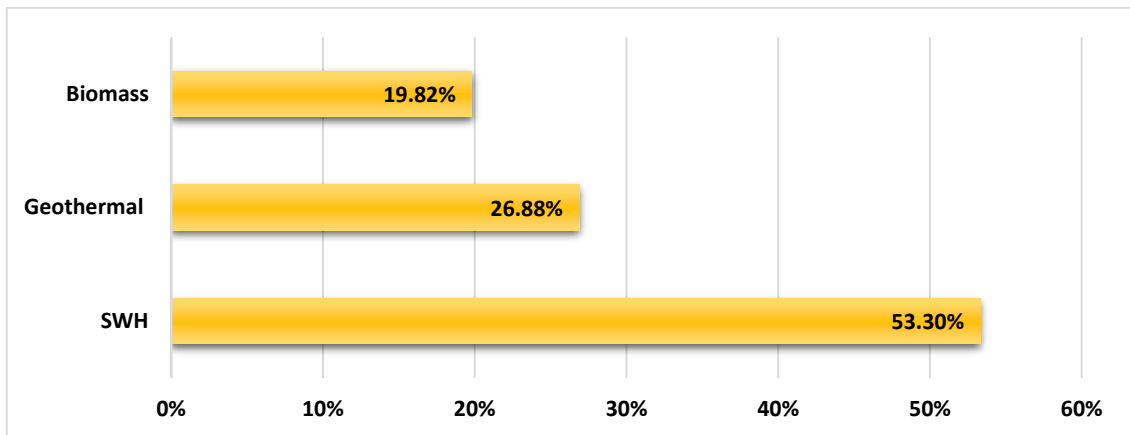


Figure (5.6): Global weights of heat generators with respect to the goal.

Global weights of electric power generators are shown in Figure (5.7). Solar PV outranks other alternatives with a weight of 36.19%, followed by wind with a weight of 18.54%, then biogas with a weight of 15.86% and WTE with a weight of 15.86%, and finally, CSP with a weight of 13.55%.

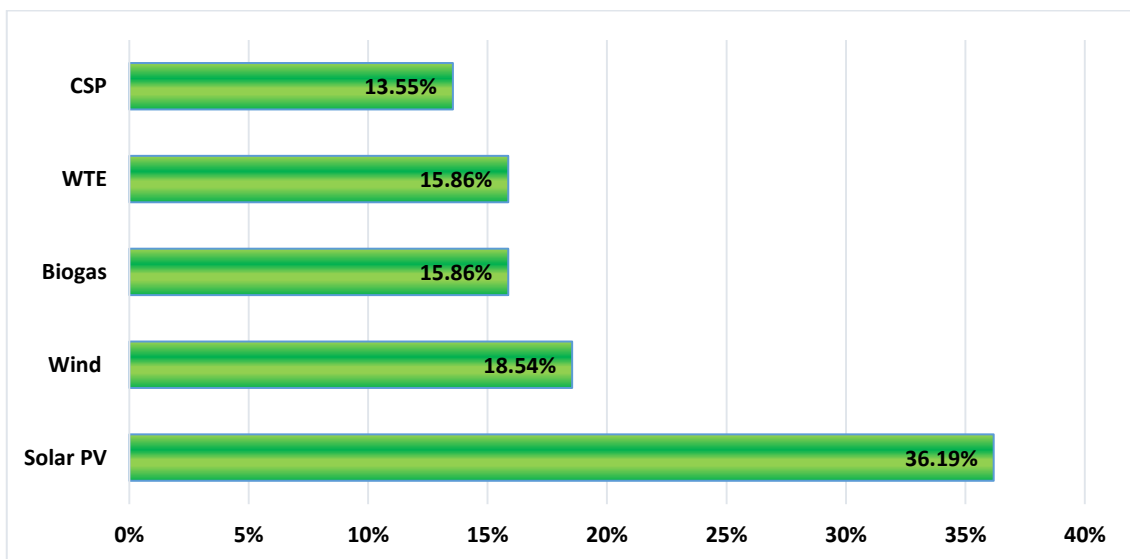


Figure (5.7): Global weights of electric power generators with respect to the goal.

Different renewable power generation technologies for electrification purposes were evaluated in the study conducted by Al Garni et al. (2016) for assessing RE technologies in Saudi Arabia. As in this study, the alternative with greater relevance was Solar PV with a high percentage of 25.6%. Second was solar thermal with 23.6%, followed by wind with 22.1%, geothermal with 13.2%, and Biomass with 15.5%. The results obtained are also in line with the work done in Algarín et al. (2017) for proper energy planning to electrify rural areas in the Caribbean region of Colombia, where four of the alternatives set in the present study were utilized: Solar PV, wind, biomass, and small hydroelectric power plants (SHPP). As in this research, the highest percentage was assigned to the Solar PV with a 45.3%. Whilst, there are differences concerning the other weights achieved: wind (23.8%), biomass (15.5%), and SHPP (15.4%). Solar PV also obtained the highest place or relevance among other alternatives in another studies (Ahmad & Tahar, 2014b; Amer & Daim, 2011b).

On the other hand, on Demirtas (2013), five renewable alternatives were used in their work to assess RE's in sustainable energy planning. In contrast to this work, wind energy comes in the first place with a weight of 29.8%, then, biomass in the second place with a weight of 19.8%, followed by geothermal with a weight of 18.4%, solar energy with a weight of 17.5%, and lastly, hydroelectric power with a weight of 14.5%.

5.5 Sensitivity Analyses

Because of the subjective evaluation carried out in this study, a sensitivity analysis is needed in order to determine the way criteria and subcriteria rankings affect the overall scores of the eight sustainable energy alternatives. Apart from the default scenario, as depicted in Figure (5.8), eight other scenarios were examined by an aid of expert choice.

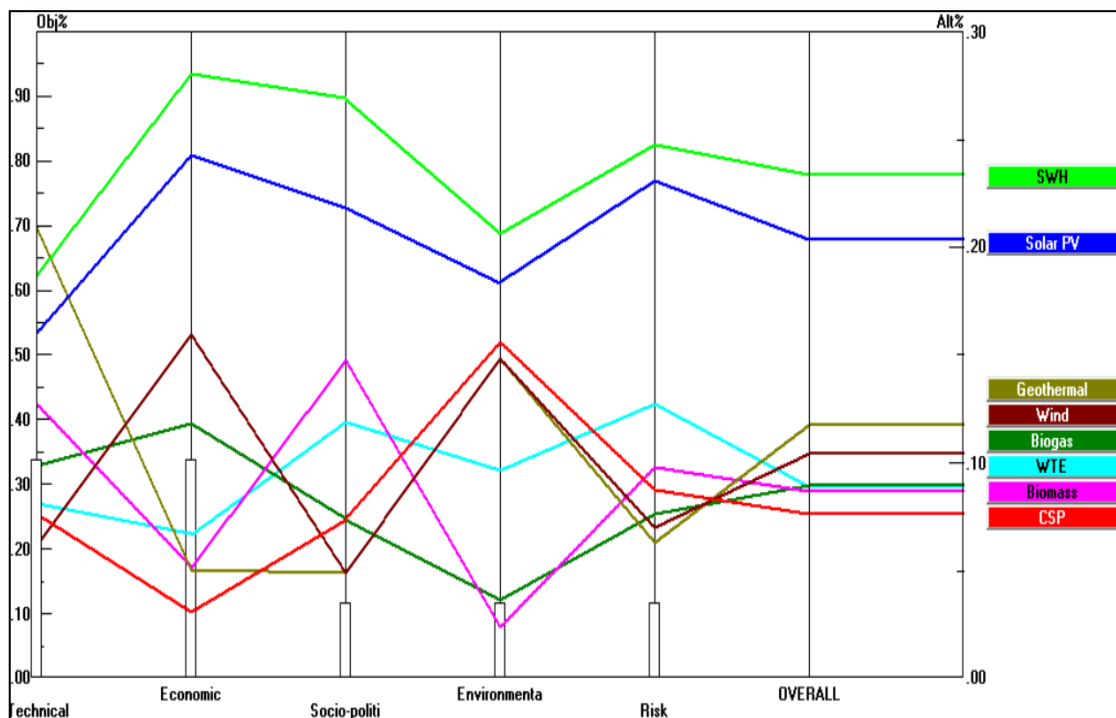


Figure (5.8): Performance sensitivity of alternatives for the proposed model.

In the first scenario, the five decision criteria are considered of equal importance; that is, each criteria have a 20% weight. Results of this scenario indicates that WTE energy became in the fifth place with a weight of 9.9%, then, CSP in the sixth place with weight of 9.2%, and then, biogas in the last place with a weight of 7.6%. In other hand, the remaining alternatives remain in the same order compared to default case. Results are illustrated in Figure (5.9).

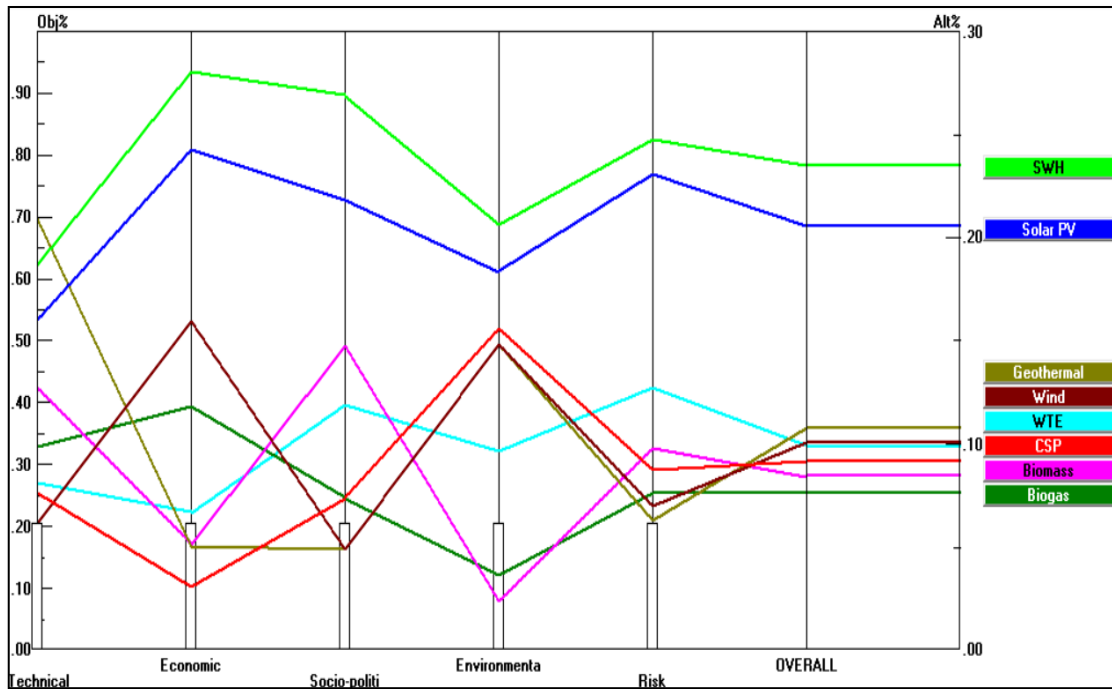


Figure (5.9): Performance sensitivity of alternatives with equal criteria weights.

Technical and economic criteria are the most considerable aspects in energy planning process among other evaluation standards, this is obvious in Table (3.3) in section titled: Selection of Criteria and Subcriteria. So, in this scenario, RE alternatives were evaluated with regard to technical and economic criteria, each had a 50% weight. Figure (5.10) revealed that solar PV, SWH, geothermal, wind, biogas, and CSP keep their ranks as in default scenario, while biomass became in the sixth place with a weight of 9% and WTE in the seventh place with a weight of 7.4%.

Reliance on renewable technologies for electricity generation will enhance the national economic level and improve the standard of living since Palestinian Territories depend on external sources to fulfill its energy needs. In this scenario, weights of economic criteria were increased to 40% whereas the other criteria have an equal weight of 15%. Considering higher

economic weight of economic criteria, as shown in Figure (5.11), resulted in rank change for wind (11.4%), geothermal (9.5%), WTE (9.2%), biogas (8.6%), CSP (7.8%), and biomass (7.7%). Whereas, other alternatives keep their ranks.

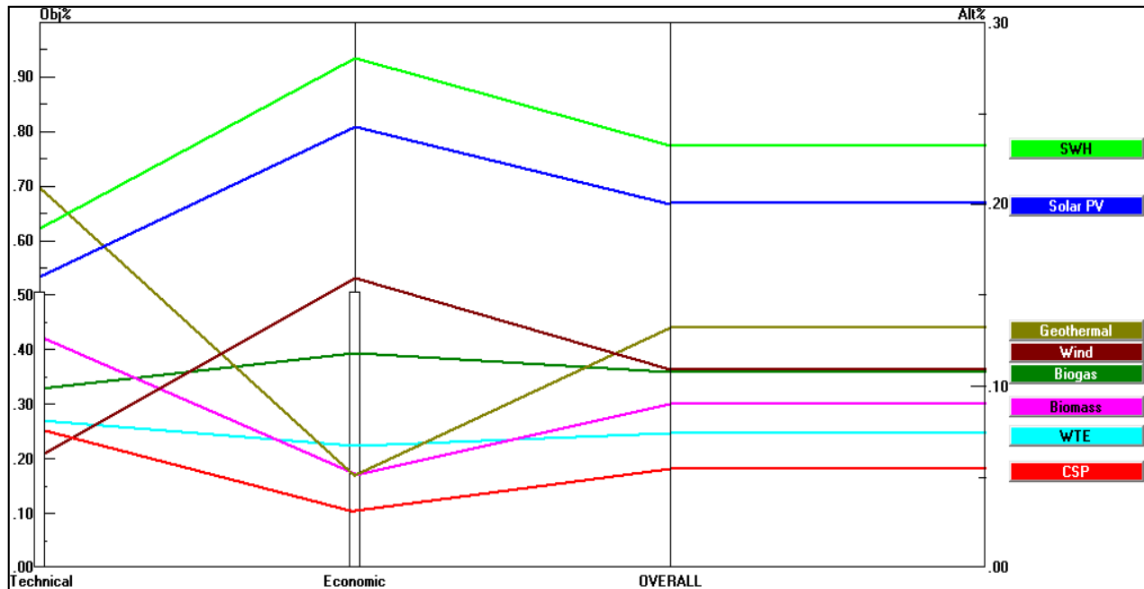


Figure (5.10): Performance sensitivity of alternatives with equal weights for technical and economic criteria.

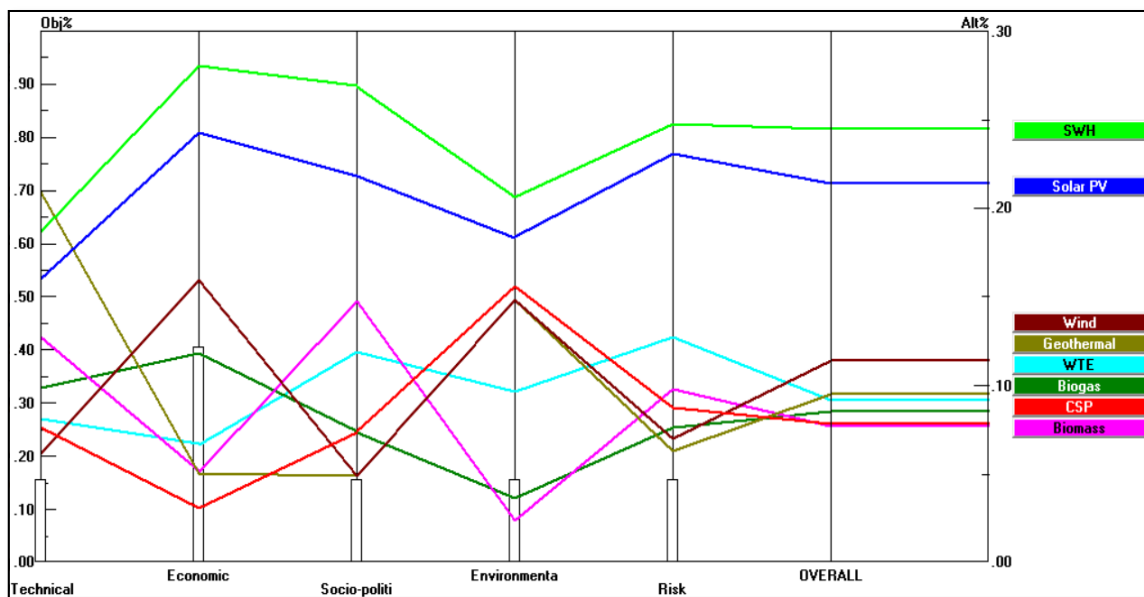


Figure (5.11): Performance sensitivity of alternatives considering higher weight of economic criteria.

Technical aspect is an important issue that must be considerable in energy planning. In this scenario, higher technical weight were considered (40%) and equal weights for the other criteria (15%). Figure (5.12) revealed that SWH (22.4%), solar PV (19.5%), and geothermal (13.1%) are most technically solutions as in default case whereas biogas (8.1%) became the least technically solution. Rank of the rest technologies have been changed as WTE (9.5%), biomass (9.4%), wind (9.2%), and CSP (8.8%).

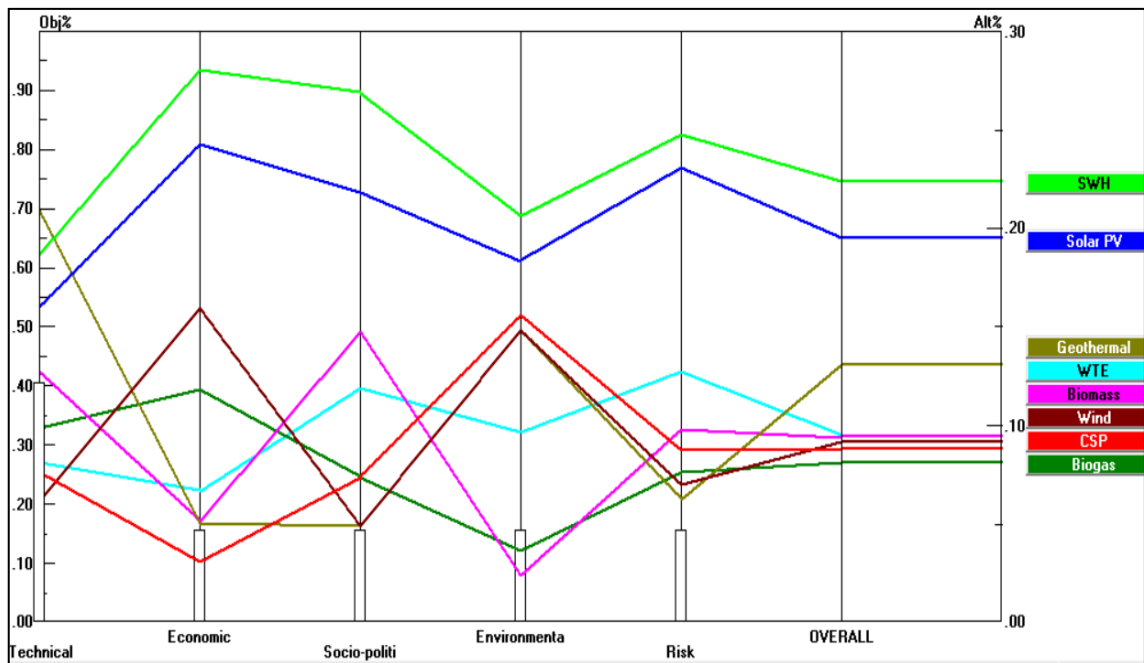


Figure (5.12): Performance sensitivity of alternatives considering higher weight of technical criteria.

In order to attain the aim of sustainability and to achieve a widespread inclusion of RE technologies in the present electrification project, thoughtful consideration in energy planning should be given to socio-political traits. Performance of RE alternatives by considering a higher weight of socio-political criteria (40%) and equal weight for the other criteria (15%) are shown in Figure (5.13). Under this scenario, WTE energy

among biomass, geothermal, wind, CSP and biogas, became in the first place with a weight of 10.3%. Then, biomass with a weight of 9.9%, then geothermal with a weight of 9.4%, after that wind with a weight of 8.9%, CSP with a weight of 8.7%, and lastly biogas with a weight of 7.6%. In other hand, SWH, and Solar PV keep their places with weights of 24.3%, and 20.8%, respectively.

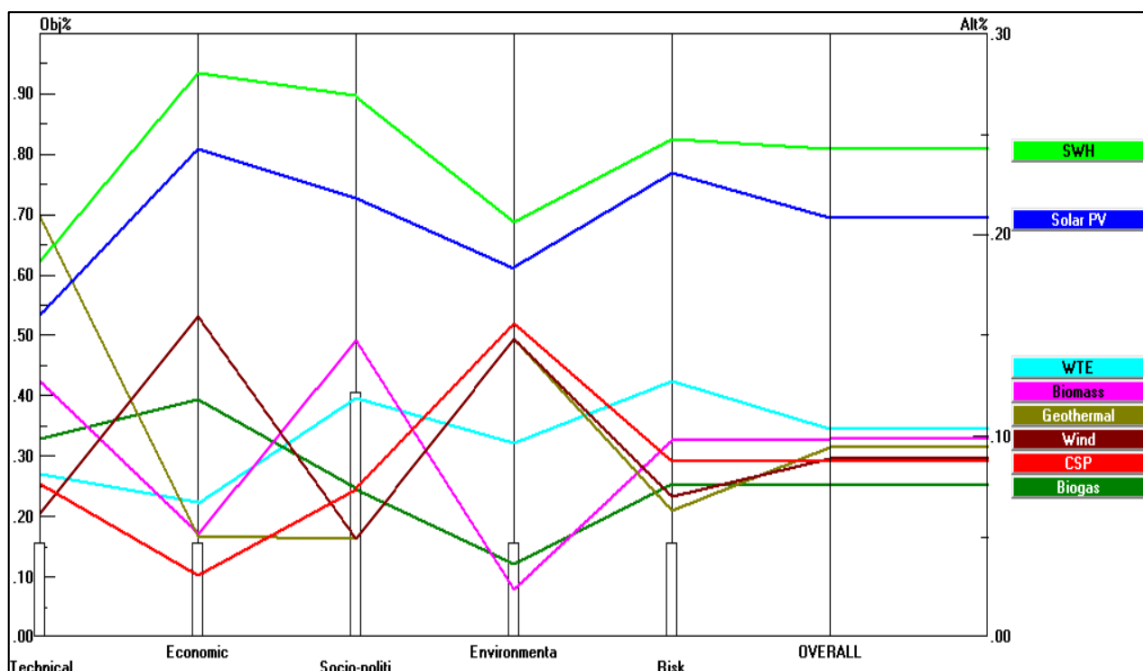


Figure (5.13): Performance sensitivity of alternatives considering higher weight of socio- political criteria.

Environmental criteria have gained a rapid pace of development and growth in various parts of the world as it let people to recognize the importance of environment and to perceive their negative impact on it. Sustainable energy encourages people to produce energy in the most environmentally friendly way, in addition to repair damaged environment and to develop possibilities and appropriate solutions in the event of any damage. Consequently, RE technologies were synthesized with respect to

goal considering higher weight of socio- political criteria (40%) and equal weights for the remaining alternatives (15%). Applying this scenario, as shown in Figure (5.14), resulted in keep SWH (22.6%), solar PV (19.9%), Geothermal (12%), wind (11.6%), WTE (9.8%), and biomass (6.6%) in their places, whereas CSP places in the fifth order with a weight of 11.1%, and biogas in the last order with a weight of 6.4%.

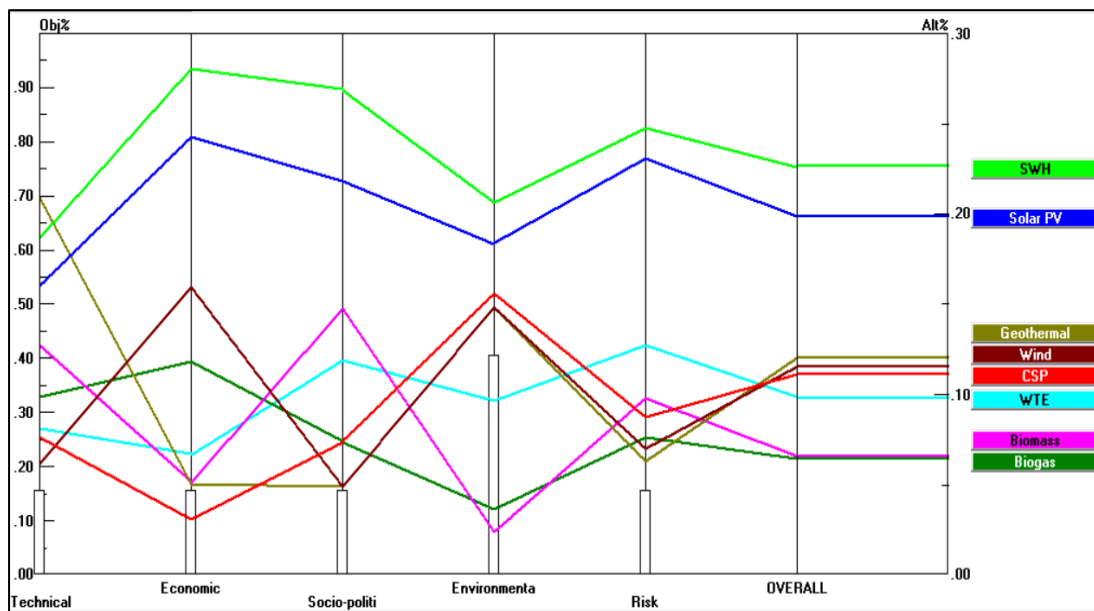


Figure (5.14): Performance sensitivity of alternatives considering higher weight of environmental criteria.

Risk associated with an implementation of a RE project must not be neglected since it may frustrate the overall project. In this scenario, we will study the effect of an increase in the weight of risk criteria on the overall alternatives rankings. Risk criteria get a weight of 40% while the other alternatives get a weight of 15%. Under this scenario, SWH, Solar PV, and biomass keep their places with weight of 23.8%, 21.2%, 8.8%, respectively. In other hand, WTE have a weight of 10.6%, then geothermal with a weight of 9.6%, then wind with a weight of 9.3%, CSP with a

weight of 9%, and finally a biogas with a weight of 7.6%. Results of this scenario are illustrated in Figure (5.15).

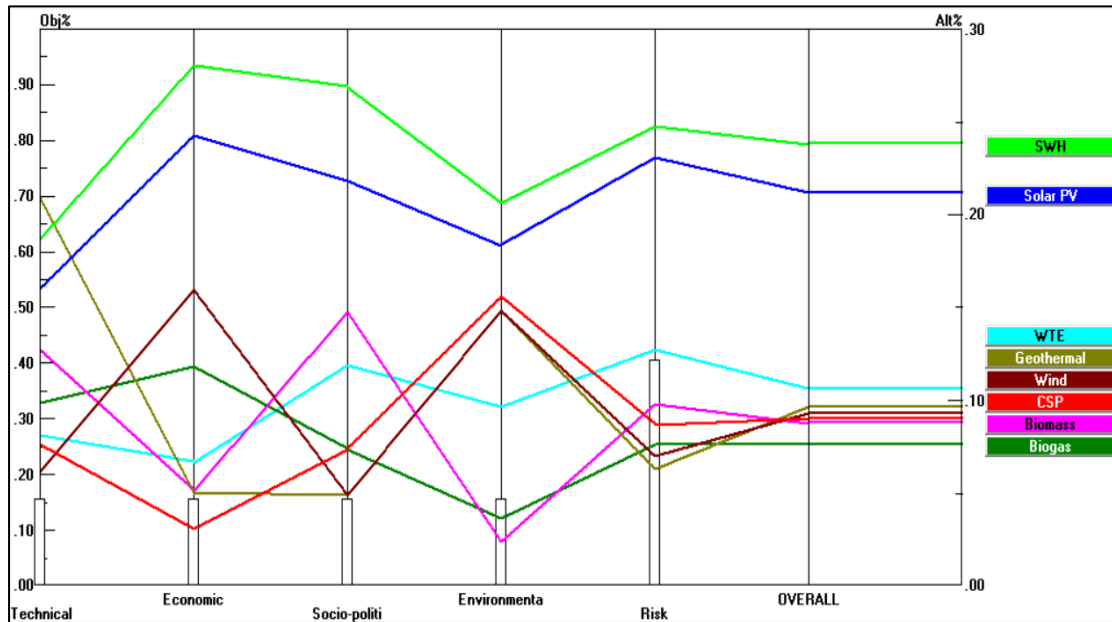


Figure (5.15): Performance sensitivity of alternatives considering higher weight of risk criteria.

Multiple and simultaneous aspects as technical, economic, social, environmental, political, and risk should be considered in energy planning in order to achieve a widespread inclusion of RE options in any electrification project for any demography of the world. For a successful implementation of any energy system, thoughtful consideration should be taken into account in technology evaluation, acquisition and deployment decisions of different renewable technologies for a country.

Various participants' background should be considered in energy planning. Heterogeneity is very crucial since it helps to obtain balanced outputs, different perspectives, and to understand the bias resulted through participation of various decision makers from different sectors. Decision

makers in this study were grouped into four categories, which are: government, industry, research, and academic.

Figure (5.16) displays the analysis of the main decision criteria per various categories of stakeholders. Participants from government, industry and academic weighted economic and technical criteria as the highest interested ones. On other hand, participants from research sector give a higher weight to technical criterion compared to the economic aspect. Socio- political criteria were rated as the highest regard to research participants, followed by academic, then by industry, and finally by government participants. Stakeholders in all fields assigned an almost equal weight to the environmental criterion. Risk achieved the lowest scores among other criteria. Government participants give the highest score to the risk criterion, followed by researchers, then by industry participants, and lastly by academics.

Technical and economic criteria have gained importance from all decision makers except researchers who gave the same weights to economic and socio-political criteria, and this is obvious in Table (5.7). Preference of technical and economic aspects is due to maximize the amounts of energy produced and to generate profits. However, other aspects as socio- political, environmental and risk are less rated than others despite their importance to gain the participation of local residents.

Table (5.7): Weights of criteria with respect to each category of decision makers.

Decision makers	Technical	Economic	Socio-political	Environmental	Risk
Government	0.34	0.34	0.073	0.123	0.123
Industry	0.364	0.364	0.091	0.091	0.091
Research	0.369	0.206	0.206	0.109	0.109
Academic	0.354	0.354	0.145	0.09	0.058

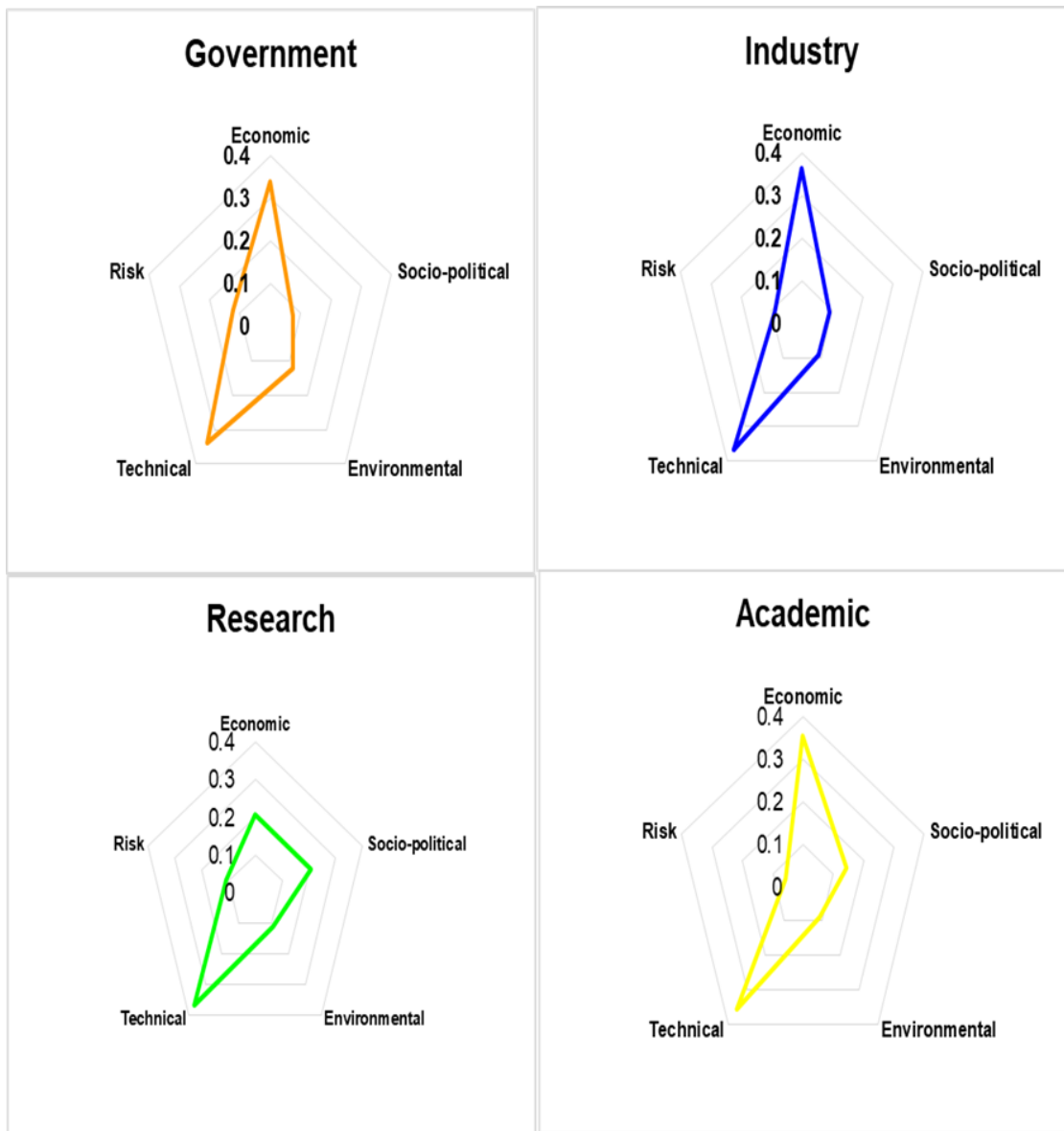


Figure (5.16): Performance of each criteria by experts' categories.

Chapter Six

Conclusions and Recommendations

6.1 Chapter Overview

This chapter exhibits a summary for the study's contents through conclusions. Also, discusses the contribution of this thesis, limitations that were encountered in this research, and also it suggests recommendations, and includes suggestions for future studies.

6.2 Conclusions

Decisions regarding the selection of sustainable energy are very complex. This is due to multi- facets nature of energy mix planning problems. Besides, complexity arises from considering many interacted factors in planning as irreversibility of decisions, long planning horizons, and uncertainty of energy demands, recourse availability, technology evaluation, selection, acquisition, and deployment. In Palestinian Territories, dependence on RE for electricity generation and for sustainable development is very low. Energy demand is going to increase in future. Therefore, for assuring a steady electrical supply, country must incorporate RE alternatives in energy planning.

In this study, MCDM approach following AHP methodology was adopted for prioritization and ranking of available renewable solutions. AHP approach has been used for the first time in energy sector of Palestinian context. Solar PV, SWH, CSP, wind, geothermal, biomass, biogas and

WTE were evaluated with respect to five criteria, which are: technical, economic, socio-political, environmental and risk. Furthermore, these criteria were divided into 22 sub-criteria for which each alternative was prioritized. Quantitative and qualitative data were combined for the overall assessment. In prioritization, quantitative data were used for the measurable data whereas experts' judgments were utilized in the qualitative cases. Survey instrument was distributed to decision makers from private sectors, universities, governments, and industry. They were asked to give their weights and opinions for evaluating criteria, subcriteria, and alternative whenever there is no available measurable data.

Results of the assessment model indicates that PBP, LCOE and capital cost are the most important subcriteria from economical aspects because of the expected economic benefits from applying these alternatives, and due to the current economic recession and the fragile economic situation of Palestinian context. Efficiency, safety of energy system, infrastructure, and reliability were ranked as the most preferable subcriteria from technical aspects. Considering technical and economic criteria and their subsequent subcriteria emphasizes on the importance of adoption them in energy planning to avoid their associated risk, and thus failure of energy project.

Among eight alternatives being considered in this study, SWH followed by solar PV are the most promising RE technologies for Palestinian Territories. This is due to their exceptional performance. Geothermal and wind energy were ranked in third, and fourth place, respectively. WTE and

biogas come in the next place with the same rankings. Moreover, Results of the proposed model indicated that biomass, and lastly CSP had modest performance in almost all criteria and subcriteria, and thus they get the lowest rankings. Therefore, SWH, solar PV should be considered as sustainable solutions for the long run by Palestinian's government. Less importance in energy road mapping process should be given to WTE, biogas, biomass and geothermal.

Results of this study are compatible with Palestinian energy's strategy, which aims to generate 10% of the electricity through RE sources by the year 2020, distributed as the following: 34.6% from solar PV, 33.8% from wind energy, 16.2% from WTE, and 15.4% from CSP. However, decision makers should consider biogas energy in their future energy strategy to produce electricity from renewables, and give it the same importance as WTE, while least importance should be given to CSP.

Utilization of RE's will significantly help Palestinian Territories to reduce dependence on the imported conventional fossil fuels, improve living standards, create job opportunities, reinforce economic growth of the country, and maintain the environmental sustainability. Applying these technologies on large and small scale will help to overcome the electricity shortage and to enhance energy security. There are many regions in Palestinian regions without electricity and adoption of these technologies will work as a solution for their problems.

Utilization of multi- criteria decision tools is very important for planners because this will facilitate the analysis of energy dilemma from multi perspectives and to integrate different stakeholders' standpoints. This, in turn, will lead to get the best optimal solutions, increase consensus, creditability and acceptability. It is obvious that there is no single renewable alternatives optimal for the whole region but a combination of different alternatives will reduce energy dependence, provide diversity, system redundancy, and provide a long run sustainable plan.

6.3 Recommendations and Future Work

The assessment model can be used for prioritization of different renewable technologies for energy production. It is recommended to employ AHP based assessment model for the next national and regional green energy roadmaps. In future researches, local data can be used in analysis to enhance model realism and accuracy. Moreover, Future researches can be executed by adopting different multi- criteria decision making tools such as ANP, fuzzy ELECTRE or fuzzy TOPSIS for comparative purposes.

6.4 Limitations of the Study

This study contains some limitations, which can be summarized as the following: There is no enough local data that can be used in the analysis process. So, in this research, we depended on external resources such as IRENA, IEA, and literature for ranking and evaluating renewable alternatives with respect to subcriteria. In addition, the number of

participants in the evaluation process is limited, as this study was based on a small sample.

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Appendices

Appendix A

Selecting the best renewable energy technologies to generate electricity in the Palestinian Territories							
Part 1							
Goal	The goal of this study is to assist decision makers and any party responsible for energy planning in Palestinian Territories by identifying the best renewable alternative for sustainable development through evaluation of the overall system mix for energy suppliers.						
Name:	Specialization:			Years of Experience:			
Sector	Palestinian Energy and Natural Resources Authority	Palestinian Electricity Transmission Company	Electricity Distribution Company	Energy Research Center	Academics	NGO's	Private Sector
Direction	Give a weight for each of the following renewable energy technologies from 1 to 9 based on your opinion in the following parts.						
Scale description	1 indicates the minimum value, whereas 9 indicates the maximum value.						
Example	Weight each of the following fruits based on your preferable taste.						
	Banana	Apple	Orange	Grape	Water melon		
	5	1	8	9	6		
Part 2: Weight each of the following criteria based on their importance for the goal: selection, evaluation and ranking of renewable energy technologies for Palestinian Territories.							
Technical criteria	Economic criteria	Socio- Political criteria		Environmental criteria	Risk criteria		

Part 14: Weight each of the following energy alternatives taking into account alternative with <u>less affected by land political categorization (A, B, C).</u>							
Solar photovoltaic	Concentrated solar power	Solar water heater(evacuated tube)	Wind energy	Geothermal energy	Biomass	Biogas	Waste- to- energy
Part 15: Weight each of the following energy alternatives taking into account alternative with <u>higher local legal framework maturity.</u>							
Solar photovoltaic	Concentrated solar power	Solar water heater(evacuated tube)	Wind energy	Geothermal energy	Biomass	Biogas	Waste- to- energy
Part 16							
Please <u>add</u> any criteria you feel it should be considered in the analysis:							
Please <u>remove</u> any criteria you feel it should not be considered in the analysis:							

Appendix B

اختيار أفضل تقنيات الطاقة المتجددة لتوليد الطاقة الكهربائية في الأراضي الفلسطينية							
القسم الأول							
الهدف من الدراسة هو مساعدة صانعي القرار وأي جهة مسؤولة عن تخطيط الطاقة في فلسطين في تحديد أفضل بديل متجدد للتنمية المستدامة وذلك من خلال تقييم بدائل الطاقة المختلفة.							
عدد سنوات الخبرة:			التخصص:			الاسم:	
مركز بحوث الطاقة	اكاديمي	قطاع خاص	شركة توزيع كهرباء الشمال	شركة النقل الكهربائية	سلطة الطاقة والموارد البيئية	NGO's	القطاع
الوصف: : ضع وزناً لكل خيار من الخيارات من 1 إلى 9 بناءً على رأيك في الأجزاء التالية. 1 يشير إلى الحد الأدنى، بينما 9 تشير إلى الحد الأعلى.							
مثال: ضع وزناً لكل من الفواكه التالية بناءً على الطعم المضل لديك							
	موز	تفاح	برتقال	عنب	بطيخ		
	5	1	8	9	6		
القسم الثاني: اختر وزناً لكل معيار من المعايير التالية بناءً على أهميتها بالنسبة لاختيار وتقييم تقنيات الطاقة المتجددة في الأراضي الفلسطينية. (المعيار الأفضل في تحقيق هذا الهدف يأخذ أعلى وزن وهو 9)							
معايير المخاطر	المعايير البيئية	المعايير الاجتماعية والسياسية	المعايير الاقتصادية	المعايير الفنية			
القسم الثالث: اختر وزناً لكل معيار من المعايير التالية بناءً على أهميتها بالنسبة للجانب الفني. (أفضل معيار يجب أخذه بعين الاعتبار عند النظر إلى الجانب الفني يحصل على أعلى وزن وهو 9)							
كفاءة الطاقة	نضج نظام الطاقة	توافر نظام الطاقة	سلامة نظام الطاقة	توافر البنية التحتية	موثوقية نظام الطاقة	تعقيد نظام الطاقة	
القسم الرابع: اختر وزناً لكل معيار من المعايير التالية بناءً على أهميتها بالنسبة للجانب الاقتصادي. (أفضل معيار يجب أخذه بعين الاعتبار عند النظر إلى الجانب الاقتصادي يحصل على أعلى وزن وهو 9)							
تكلفة رأس المال	التنمية الاقتصادية الوطنية	فترة استرداد المال	التكلفة المستوية للطاقة (LCOE)	التكاليف التشغيلية وتكاليف الصيانة			

<p>القسم الخامس: اختر وزنا لكل معيار من المعايير التالية بناء على أهميتها بالنسبة للجوانب الاقتصادية والاجتماعية. (أفضل معيار يجب أخذه بعين الاعتبار عند النظر الى الجوانب الاقتصادية والاجتماعية يحصل على أعلى وزن وهو 9)</p>							
قبول السكان المحليين بنظام الطاقة		خلق فرص العمل		تعزيز أمن الطاقة الوطني			
<p>القسم السادس: اختر وزنا لكل معيار من المعايير التالية بناء على أهميتها بالنسبة للجانب البيئي. (أفضل معيار يجب أخذه بعين الاعتبار عند النظر الى الجانب البيئي يحصل على أعلى وزن وهو 9)</p>							
تقليل الانبعاثات التي تضر بالبيئة		متطلبات نظام الطاقة من موارد الارض والمياه		أثر نظام الطاقة على البيئة المحيطة			
<p>القسم السابع: اختر وزنا لكل معيار من المعايير التالية بناء على أهميتها بالنسبة لجانب المخاطر. (أفضل معيار يجب أخذه بعين الاعتبار عند النظر الى جانب الخطر يحصل على أعلى وزن وهو 9)</p>							
أثر الصراعات المسلحة على نظام الطاقة		مخاطر الاستثمار		التصنيف السياسي للأراضي (أ ، ب ، ج)		نضج الإطار القانوني المحلي	
<p>القسم الثامن: بالنسبة الى توافر البنية التحتية، قيم كلا من تقنيات الطاقة المتجددة التالية بناء على الافضلية. (البديل الذي يتميز بأعلى توافر للبنية التحتية يأخذ أعلى وزن وهو 9)</p>							
الخلايا الشمسية (Solar PV)	الطاقة الشمسية المركزة (CSP)	سخان مياه بالطاقة الشمسية (أنبوب مفرغ) Solar water heater	طاقة الرياح	الطاقة الحرارية الأرضية	الكتلة الحيوية (Biomass)	الغاز الحيوي (Biogas)	تحويل النفايات الى طاقة (waste-to-energy)

القسم التاسع: قيم كلا من تقنيات الطاقة المتجددة التالية بناء على أهميتها في تحقيق التنمية الاقتصادية الوطنية. (أفضل بديل في تحقيق التنمية الاقتصادية الوطنية يأخذ أعلى وزن وهو 9)							
تحويل النفايات الى طاقة (waste-to-energy)	الغاز الحيوي (Biogas)	الكتلة الحيوية (Biomass)	الطاقة الحرارية الأرضية	طاقة الرياح	سخان مياه بالطاقة الشمسية (أنبوب مفرغ) Solar water heater	الطاقة الشمسية المركزة (CSP)	الخلايا الشمسية (Solar PV)
القسم العاشر: قيم كلا من تقنيات الطاقة المتجددة التالية بناء على أهميتها في تحقيق أمن وطن أفضل. (أفضل بديل في تحقيق الأمن الوطني يأخذ أعلى وزن وهو 9)							
تحويل النفايات الى طاقة (waste-to-energy)	الغاز الحيوي (Biogas)	الكتلة الحيوية (Biomass)	الطاقة الحرارية الأرضية	طاقة الرياح	سخان مياه بالطاقة الشمسية (أنبوب مفرغ) Solar water heater	الطاقة الشمسية المركزة (CSP)	الخلايا الشمسية (Solar PV)
القسم الحادي عشر: قيم كلا من تقنيات الطاقة المتجددة التالية مع مراعاة البديل ذو التأثير الأفضل على البيئة المحيطة به. (البديل الذي يتميز بأفضل تأثير على البيئة المحيطة به يأخذ أعلى وزن وهو 9)							
تحويل النفايات الى طاقة (waste-to-energy)	الغاز الحيوي (Biogas)	الكتلة الحيوية (Biomass)	الطاقة الحرارية الأرضية	طاقة الرياح	سخان مياه بالطاقة الشمسية (أنبوب مفرغ) Solar water heater	الطاقة الشمسية المركزة (CSP)	الخلايا الشمسية (Solar PV)

القسم الثاني عشر: قيم كلا من تقنيات الطاقة المتجددة التالية مع مراعاة البديل الأقل تأثيراً بالصراعات المسلحة. (البديل الأقل تأثيراً بالصراعات المسلحة يأخذ أعلى وزن وهو 9)							
تحويل النفايات الى طاقة (waste-to-energy)	الغاز الحيوي (Biogas)	الكتلة الحيوية (Biomass)	الطاقة الحرارية الأرضية	طاقة الرياح	سخان مياه بالطاقة الشمسية (أنبوب مفرغ) Solar water heater	الطاقة الشمسية المركزة (CSP)	الخلايا الشمسية (Solar PV)
القسم الثالث عشر: قيم كلا من تقنيات الطاقة المتجددة التالية مع مراعاة البديل الذي يتمتع بأقل خطر للاستثمار. (البديل الذي يتمتع بأقل خطر للاستثمار يأخذ أعلى وزن وهو 9)							
تحويل النفايات الى طاقة (waste-to-energy)	الغاز الحيوي (Biogas)	الكتلة الحيوية (Biomass)	الطاقة الحرارية الأرضية	طاقة الرياح	سخان مياه بالطاقة الشمسية (أنبوب مفرغ) Solar water heater	الطاقة الشمسية المركزة (CSP)	الخلايا الشمسية (Solar PV)
القسم الرابع عشر: قيم كلا من تقنيات الطاقة المتجددة التالية مع الأخذ في عين الاعتبار التقنيات الأقل تأثيراً بالتصنيف السياسي للأراضي (أ ، ب ، ج). (البديل الأقل تأثيراً بالتصنيف السياسي للأراضي يحصل على أعلى وزن وهو 9)							
تحويل النفايات الى طاقة (waste-to-energy)	الغاز الحيوي (Biogas)	الكتلة الحيوية (Biomass)	الطاقة الحرارية الأرضية	طاقة الرياح	سخان مياه بالطاقة الشمسية (أنبوب مفرغ) Solar water heater	الطاقة الشمسية المركزة (CSP)	الخلايا الشمسية (Solar PV)

القسم الخامس عشر: قيم كلا من تقنيات الطاقة المتجددة التالية مع الأخذ في الاعتبار البدائل التي تتمتع بنضج الاطار القانوني المحلي. (البديل الذي يتمتع بأعلى نضج بالنسبة إلى الاطار القانوني المحلي يأخذ أعلى وزن وهو 9)

تحويل النفايات الى طاقة (waste- to- energy)	الغاز (Biogas) الحيوي	الكتلة الحيوية (Biomass)	الطاقة الحرارية الأرضية	طاقة الرياح	سخان مياه بالطاقة الشمسية (أنبوب مفرغ) Solar water heater	الطاقة الشمسية (CSP) المركزة	الخلايا الشمسية (Solar PV)
القسم السادس عشر							
يرجى إضافة أي معيار تشعر بضرورة أخذه بعين الاعتبار في التحليل:							
يرجى حذف أي معيار تشعر بضرورة عدم أخذه بعين الاعتبار في التحليل:							

Annexes

Annex table 1: Technical criteria.

Technical criteria		
NO.	Subcriteria	References
1	Efficiency	(Abdullah & Najib, 2014; Ahmad & Tahar, 2014b; Baris & Kucukali, 2012; Daniel, Vishal, Albert, & Selvarsan, 2010; Demirtas, 2013; Gülçin & Sezin, 2014; Kaya & Kahraman, 2010b; Kumar, Deng, He, & Kumar, 2016; Luthra, Mangla, & Kharb, 2015; Mourmouris & Potolias, 2013; Mourmouris, Potolias, & Fantidis, 2012; Nigim et al., 2004; Rojas-Zerpa & Yusta, 2015; Rosso, Bottero, Pomarico, La Ferlita, & Comino, 2014; Shabbar, Janajreh, & Ghenai, 2014; Stein, 2013; Theodorou et al., 2010; Wang, Jing, Zhang, & Zhao, 2009; Zanuttigh et al., 2016; Zhang, Lu, & Liu, 2014)
2	Technology maturity	(Ahmad & Tahar, 2014b; Amer & Daim, 2011a; Beccali, Cellura, & Mistretta, 2003; Demirtas, 2013; Hernández-Torres, Urdaneta, & De Oliveira-De Jesus, 2015; Kahraman, Kaya, & Cebi, 2009b; Kumar et al., 2016; Pisani & Villacci, 2011; Shen, Lin, Li, & Yuan, 2010; Theodorou et al., 2010; Wang et al., 2009; Zanuttigh et al., 2016)
3	Spare parts availability	(Aragonés-Beltrán, Chaparro-González, Pastor-Ferrando, & Pla-Rubio, 2014; Daim et al., 2009; Gul & Chaudhry, 2014; Hernández-Torres et al., 2015; Mourmouris & Potolias, 2013; Mourmouris et al., 2012)
4	Infrastructure	(Amer & Daim, 2011a; Aragonés-Beltrán et al., 2014; Samal & Kansal, 2015; Tasri & Susilawati, 2014)
5	Deployment time	(Ahmad & Tahar, 2014b; Amer & Daim, 2011a; Goletsis, Psarras, & Samouilidis, 2003; Kahraman et al., 2009b)
6	Expert human resource	(Amer & Daim, 2011a)
7	Resource reserves	(Ahmad & Tahar, 2014b; Amer & Daim, 2011a; Georgopoulou et al., 1997)
8	Safety of energy system	(Chatzimouratidis & Pilavachi, 2008; Kahraman et al., 2009b; Streimikiene et al., 2012; Wang et al., 2009)
9	Electricity supply availability	(Streimikiene et al., 2012)
10	Ease of decentralization	(Al Garni et al., 2016)
11	Network stability	(Elkarmi & Mustafa, 1993)
12	Safety in covering peak demand	(Brand & Missaoui, 2014; Georgopoulou et al., 1997; Streimikiene et al., 2012)
13	Reliability	(Amer & Daim, 2011a; Baris & Kucukali, 2012; Daim et al., 2009; Demirtas, 2013; Kahraman et al., 2009b; Kaya & Kahraman, 2010b; Kumar et al., 2016; Ma, Zeng, Zhang, Li, & Liu, 2015; Mourmouris & Potolias, 2013; Mourmouris et al., 2012; Rojas-Zerpa & Yusta, 2015; Shabbar et al., 2014; Zanuttigh et al., 2016)
14	Complexity	(Baris & Kucukali, 2012)
15	The duration of preparation phase	(Kahraman, Kaya, & Cebi, 2009a)
16	The duration of implementation phase	(Kahraman et al., 2009a)
17	Energy Production Capacity	(Demirtas, 2013; Kaya & Kahraman, 2010a)

Annex table 2: Economic criteria.

Economic criteria		
No.	Subcriteria	References
1	R&D cost	(Amer & Daim, 2011a)
2	Capital cost	(Abdullah & Najib, 2014; Ahmad & Tahar, 2014b; Amer & Daim, 2011a; Aragonés-Beltrán et al., 2014; Baris & Kucukali, 2012; Brand & Missaoui, 2014; Daim et al., 2009; Demirtas, 2013; Danae Diakoulaki & Karangelis, 2007; Georgopoulou et al., 1997; Goletsis et al., 2003; Gülçin & Sezin, 2014; Hernández-Torres et al., 2015; Kahraman et al., 2009b; Kaya & Kahraman, 2010b; Kumar et al., 2016; Mizanur, Paatero, & Lahdelma, 2013; Mourmouris & Potolias, 2013; Mourmouris et al., 2012; Nigim et al., 2004; Pisani & Villacci, 2011; Ribeiro, Ferreira, & Araújo, 2012; Rojas-Zerpa & Yusta, 2015; Rosso et al., 2014; Shabbar et al., 2014; Shen et al., 2010; Stein, 2013; Streimikiene et al., 2012; Tasri & Susilawati, 2014; Theodorou et al., 2010; Wang et al., 2009)
3	Operations & maintenance (O&M) cost	(Abdullah & Najib, 2014; Ahmad & Tahar, 2014b; Aragonés-Beltrán et al., 2014; Brand & Missaoui, 2014; Demirtas, 2013; Georgopoulou et al., 1997; Guerrero-Liquet, Sánchez-Lozano, García-Cascales, Lamata, & Verdegay, 2016; Gul & Chaudhry, 2014; Gülçin & Sezin, 2014; Hernández-Torres et al., 2015; Kahraman et al., 2009b; Kang, Hung, Pearn, Lee, & Kang, 2011; Kaya & Kahraman, 2010b; Kumar et al., 2016; Ma et al., 2015; Mizanur et al., 2013; Mourmouris & Potolias, 2013; Mourmouris et al., 2012; Ribeiro et al., 2012; Rojas-Zerpa & Yusta, 2015; Rosso et al., 2014; Stein, 2013; Streimikiene et al., 2012; Wang et al., 2009; Zanuttigh et al., 2016)
4	Cost of grid connection	(Streimikiene et al., 2012)
5	Fuels cost	(Brand & Missaoui, 2014; Kaya & Kahraman, 2010b; Ribeiro et al., 2012; Streimikiene et al., 2012; Wang et al., 2009)
6	Market maturity	(Beccali et al., 2003; Elkarmi & Mustafa, 1993; Kahraman et al., 2009b)
7	National economic development	(Amer & Daim, 2011a; Brand & Missaoui, 2014; Nigim et al., 2004; Ribeiro et al., 2012)
8	Availability of fund	(Goletsis et al., 2003; Kahraman et al., 2009b)
9	Payback Period	(Amer & Daim, 2011b; Demirtas, 2013; Guerrero-Liquet et al., 2016; Gülçin & Sezin, 2014; Kahraman et al., 2009b; Kaya & Kahraman, 2010b; Luthra et al., 2015; Ma et al., 2015; Mourmouris & Potolias, 2013; Rosso et al., 2014)
10	Net present value (NPV)	(Amer & Daim, 2011b; Hernández-Torres et al., 2015; Kahraman et al., 2009a; Mourmouris & Potolias, 2013; Mourmouris et al., 2012; Rojas-Zerpa & Yusta, 2015)
11	Rate of Return (ROR)	(Büyükoçkan & Güleriyüz, 2014; Kahraman et al., 2009a; Rosso et al., 2014; Tasri & Susilawati, 2014)
12	Levelized Cost of Energy (LCOE)	(Hernández-Torres et al., 2015; Luthra et al., 2015)

Annex table 3: Socio- political criteria.

Socio- political criterion		
No.	Subcriteria	References
1	Acceptability of local residents	(Abdullah & Najib, 2014; Ahmad & Tahar, 2014b; Amer & Daim, 2011a; Baris & Kucukali, 2012; Chatzimouratidis & Pilavachi, 2008; Demirtas, 2013; Goletsis et al., 2003; Gul & Chaudhry, 2014; Gülçin & Sezin, 2014; Hernández-Torres et al., 2015; Kahraman et al., 2009b; Kumar et al., 2016; Luthra et al., 2015; Mizanur et al., 2013; Mourmouris & Potolias, 2013; Mourmouris et al., 2012; Pisani & Villacci, 2011; Rojas-Zerpa & Yusta, 2015; Streimikiene et al., 2012; Tasri & Susilawati, 2014; Theodorou et al., 2010; Wang et al., 2009; Zanuttigh et al., 2016)
2	Employment creation	(Abdullah & Najib, 2014; Ahmad & Tahar, 2014b; Amer & Daim, 2011a; Baris & Kucukali, 2012; Beccali et al., 2003; Brand & Missaoui, 2014; Chatzimouratidis & Pilavachi, 2008; Demirtas, 2013; Georgopoulou et al., 1997; Gul & Chaudhry, 2014; Gülçin & Sezin, 2014; Kahraman et al., 2009b; Kaya & Kahraman, 2010b; Kumar et al., 2016; Ma et al., 2015; Mizanur et al., 2013; Mourmouris & Potolias, 2013; Mourmouris et al., 2012; Rojas-Zerpa & Yusta, 2015; Rosso et al., 2014; Samal & Kansal, 2015; Stein, 2013; Streimikiene et al., 2012; Wang et al., 2009)
3	Energy for rural health and education	(Amer & Daim, 2011a; Kumar et al., 2016; Luthra et al., 2015; Mourmouris & Potolias, 2013)
4	Installation on indigenous lands	(Abdullah & Najib, 2014; Daim et al., 2009; Kang et al., 2011; Luthra et al., 2015; Rosso et al., 2014)
5	Impact on human health	(Streimikiene et al., 2012)
6	Feasibility	(Beccali et al., 2003; Goletsis et al., 2003; Kahraman et al., 2009b)
7	Compatibility with the national energy policy	(Kahraman et al., 2009b; Theodorou et al., 2010)(Georgopoulou et al., 1997; Goletsis et al., 2003)
8	National energy security/energy independency	(Amer & Daim, 2011a; Brand & Missaoui, 2014; Danae Diakoulaki & Karangelis, 2007; Stein, 2013; Streimikiene et al., 2012; Theodorou et al., 2010)
9	Maintain leading position as energy supplier	(Al Garni et al., 2016)
10	Labor impact	(Kahraman et al., 2009a)

Annex table 4: Environmental criteria.

Environmental criteria		
No.	Subcriteria	References
1	CO2 emissions	(Abdullah & Najib, 2014; Ahmad & Tahar, 2014b; Amer & Daim, 2011a; Baris & Kucukali, 2012; Brand & Missaoui, 2014; Demirtas, 2013; Danae Diakoulaki & Karangelis, 2007; Gülçin & Sezin, 2014; Hernández-Torres et al., 2015; Kahraman et al., 2009b; Kaya & Kahraman, 2010b; Luthra et al., 2015; Ma et al., 2015; Mizanur et al., 2013; Mourmouris & Potolias, 2013; Mourmouris et al., 2012; Pisani & Villacci, 2011; Rojas-Zerpa & Yusta, 2015; Samal & Kansal, 2015; Shen et al., 2010; Theodorou et al., 2010; Zhang et al., 2014)
2	Requirement of land and water resources	(Ahmad & Tahar, 2014b; Amer & Daim, 2011a; Chatzimouratidis & Pilavachi, 2008; Georgopoulou et al., 1997; Gul & Chaudhry, 2014; Gülçin & Sezin, 2014; Kahraman et al., 2009b; Kaya & Kahraman, 2010b; Kumar et al., 2016; Luthra et al., 2015; Ma et al., 2015; Mizanur et al., 2013; Mourmouris & Potolias, 2013; Mourmouris et al., 2012; Rojas-Zerpa & Yusta, 2015; Rosso et al., 2014; Samal & Kansal, 2015; Shen et al., 2010; Tasri & Susilawati, 2014; Wang et al., 2009)
3	Visual impact	(Baris & Kucukali, 2012; Gülçin & Sezin, 2014; Hernández-Torres et al., 2015; Kahraman et al., 2009b; Mizanur et al., 2013; Mourmouris & Potolias, 2013; Mourmouris et al., 2012; Pisani & Villacci, 2011)
4	Hazardous waste	(Kang et al., 2011; Kaya & Kahraman, 2010b; Kumar et al., 2016; Luthra et al., 2015; Shen et al., 2010; Tasri & Susilawati, 2014)
5	Need for waste disposal	(Kahraman et al., 2009b; Streimikiene et al., 2012)
6	Disturbance of ecological balance	(Georgopoulou et al., 1997; Streimikiene et al., 2012)

Annex table 5: Risk criteria.

Risk Criteria		
No.	Subcriteria	References
1	Natural phenomena	(Aragonés-Beltrán et al., 2014; Guerrero-Liquet et al., 2016; Gul & Chaudhry, 2014; Kang et al., 2011; Pisani & Villacci, 2011)
2	Armed conflict	(Demirtas, 2013; Gülçin & Sezin, 2014; Rosso et al., 2014)
3	Investment risk	(Amer & Daim, 2011a; Aragonés-Beltrán et al., 2014; Baris & Kucukali, 2012; Gülçin & Sezin, 2014; Luthra et al., 2015; Zanuttigh et al., 2016)
4	Technological obsolescence	(Kang et al., 2011; Mourmouris & Potolias, 2013; Tasri & Susilawati, 2014)
5	Land political categorization (A, B, C)	OWN
6	Local legal framework maturity	OWN

Annex table 6: Pairwise comparison matrix of technical subcriteria with respect to technical criteria.

Technical subcriteria	Efficiency	Technology maturity	Resource availability	Safety of energy system	Infrastructure	Reliability	Complexity
Efficiency	1	2	1	1	1	1	3
Technology maturity	0.5000	1	0.5000	0.5000	0.5000	0.5000	2
Resource availability	1	2	1	1	1	1	3
Safety of energy system	1	2	1	1	1	1	3
Infrastructure	1	2	1	1	1	1	3
Reliability	1	2	1	1	1	1	3
Complexity	0.3333	0.5000	0.3333	0.3333	0.3333	0.3333	1

Annex table 7: Pairwise comparison matrix of economic subcriteria with respect to economic criteria.

Economic subcriteria	Capital cost	Operational and maintenance cost	National economic development	Payback period	Levelized cost of energy
Capital cost	1	2	2	1	1
Operational and maintenance cost	0.5000	1	1	0.5000	0.5000
National economic development	0.5000	1	1	0.5000	0.5000
Payback period	1	2	2	1	1
Levelized cost of energy	1	2	2	1	1

Annex table 8: Pairwise comparison matrix of socio- political subcriteria with respect to socio- political criteria.

Socio- political subcriteria	Acceptability of local residents	Employment creation	National energy security
Acceptability of local residents	1	1	0.5
Employment creation	1	1	0.5
National energy security	2	2	1

Annex table 9: Pairwise comparison matrix of environmental subcriteria with respect to environmental criteria.

Environmental subcriteria	CO2 emissions	Requirements of Land and water resources	Visual impact
CO2 emissions	1	1	2
Requirements of Land and water resources	1	1	2
Visual impact	0.5	0.5	1

Annex table 10: Pairwise comparison matrix of risk subcriteria with respect to risk criteria.

Risk subcriteria	Armed conflict	Investment risk	Land political categorization (A, B, C)	Local legal framework maturity
Armed conflict	1	0.5	0.3333	0.5
Investment risk	2	1	0.5	1
Land political categorization (A, B, C)	3	2	1	2
Local legal framework maturity	2	1	0.5	1

Annex table 11: Pairwise comparison matrix of alternatives with respect to efficiency subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	0.5	0.5	1	0.111	0.125	0.2	1
CSP	2	1	1	2	0.125	0.143	0.25	2
SWH	2	1	1	2	0.125	0.143	0.25	2
Wind	1	0.5	0.5	1	0.111	0.125	0.2	1
Geothermal	9	8	8	9	1	2	5	9
Biomass	8	7	7	8	0.500	1	4	8
Biogas	5	4	4	5	0.2	0.250	1	5
WTE	1	0.5	0.5	1	0.111	0.125	0.2	1

Annex table 12: Pairwise comparison matrix of alternatives with respect to technology maturity subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	7	1	2	1	0.333	2	2
CSP	0.1428	1	0.143	0.167	0.143	0.111	0.167	0.167
SWH	1	7	1	2	1	0.333	2	2
Wind	0.5	6	0.5	1	0.5	0.25	1	1
Geothermal	1	7	1	2	1	0.333	2	2
Biomass	3	9	3	4	3	1	4	4
Biogas	0.5	6	0.5	1	0.5	0.25	1	1
WTE	0.5	6	0.5	1	0.5	0.25	1	1

Annex table 13: Pairwise comparison matrix of alternatives with respect to availability subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	1	0.250	1	0.111	0.143	0.125	0.125
CSP	1	1	0.250	1	0.111	0.143	0.125	0.125
SWH	4	4	1	4	0.167	0.25	0.2	0.2
Wind	1	1	0.250	1	0.111	0.143	0.125	0.125
Geothermal	9	9	6	9	1	3	2	2
Biomass	7	7	4	7	0.333	1	0.5	0.5
Biogas	8	8	5	8	0.5	2	1	1
WTE	8	8	5	8	0.5	2	1	1

Annex table 14: Pairwise comparison matrix of alternatives with respect to safety of energy system subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	4	4	6	6	9	9	9
CSP	0.250	1	1	3	3	6	6	6
SWH	0.250	1	1	3	3	6	6	6
Wind	0.167	0.333	0.333	1	1	4	4	4
Geothermal	0.167	0.333	0.333	1	1	4	4	4
Biomass	0.111	0.167	0.167	0.25	0.25	1	1	1
Biogas	0.111	0.167	0.167	0.25	0.25	1	1	1
WTE	0.111	0.167	0.167	0.25	0.25	1	1	1

Annex table 15: Pairwise comparison matrix of alternatives with respect to infrastructure subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	4	1	5	6	4	4	4
CSP	0.250	1	0.250	2	3	1	1	1
SWH	1	4	1	5	6	4	4	4
Wind	0.200	0.500	0.200	1	2	0.5	0.5	0.5
Geothermal	0.167	0.333	0.167	0.5	1	0.333	0.333	0.333
Biomass	0.250	1	0.250	2	3	1	1	1
Biogas	0.250	1.000	0.250	2	3	1	1	1
WTE	0.250	1.000	0.250	2	3	1	1	1

Annex table 16: Pairwise comparison matrix of alternatives with respect to reliability subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	1	0.111	1	0.111	1	1	1
CSP	1	1	0.111	1	0.111	1	1	1
SWH	9	9	1	9	1	9	9	9
Wind	1	1	0.111	1	0.111	1	1	1
Geothermal	9	9	1	9	1	9	9	9
Biomass	1	1	0.111	1	0.111	1	1	1
Biogas	1	1	0.111	1	0.111	1	1	1
WTE	1	1	0.111	1	0.111	1	1	1

Annex table 17: Pairwise comparison matrix of alternatives with respect to complexity subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	1	1	1	6	6	6	9
CSP	1	1	1	1	6	6	6	9
SWH	1	1	1	1	6	6	6	9
Wind	1	1	1	1	6	6	6	9
Geothermal	0.167	0.167	0.167	0.167	1	1	1	4
Biomass	0.167	0.167	0.167	0.167	1	1	1	4
Biogas	0.167	0.167	0.167	0.167	1	1	1	4
WTE	0.111	0.111	0.111	0.111	0.25	0.25	0.25	1

Annex table 18: Pairwise comparison matrix of alternatives with respect to capital cost subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	8	0.5	1	3	5	1.000	6
CSP	0.125	1	0.111	0.125	0.167	0.250	0.125	0.333
SWH	2	9	1	2	4	6	2	7
Wind	1	8	0.5	1	3	5	1	6
Geothermal	0.333	6	0.250	0.333	1	3	0.333	4
Biomass	0.2	4	0.167	0.2	0.333	1	0.2	2
Biogas	1	8	0.5	1	3	5	1	6
WTE	0.167	3	0.143	0.167	0.25	0.5	0.167	1

Annex table 19: Pairwise comparison matrix of alternatives with respect to operational and maintenance cost subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	7	1	2	9	9	2	7
CSP	0.143	1	0.143	0.167	3	3	0.167	1
SWH	1	7	1	2	9	9	2	7
Wind	0.5	6	0.5	1	8	8	1	6
Geothermal	0.111	0.333	0.111	0.125	1	1	0.125	0.333
Biomass	0.111	0.333	0.111	0.125	1	1	0.125	0.333
Biogas	0.5	6	0.5	1	8	8	1	6
WTE	0.143	1	0.143	0.1667	3	3	0.1667	1

Annex table 20: Pairwise comparison matrix of alternatives with respect to national economic development subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	5	4	6	6	5	5	4
CSP	0.200	1	0.500	2	2	1	1	0.500
SWH	0.250	2	1	3	3	2	2	1
Wind	0.167	0.500	0.333	1	1	0.500	0.500	0.333
Geothermal	0.167	0.500	0.333	1	1	0.500	0.500	0.333
Biomass	0.200	1	0.500	2	2	1	1	0.500
Biogas	0.200	1	0.500	2	2	1	1	0.500
WTE	0.250	2	1	3	3	2	2	1

Annex table 21: Pairwise comparison matrix of alternatives with respect to pay back period subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	9	3	4	8	7	7	7
CSP	0.111	1	0.143	0.167	0.5	0.333	0.333	0.333
SWH	0.333	7	1	2	6	5	5	5
Wind	0.25	6	0.5	1	5	4	4	4
Geothermal	0.125	2	0.167	0.2	1	0.5	0.5	0.5
Biomass	0.143	3	0.2	0.25	2	1	1	1
Biogas	0.143	3	0.2	0.25	2	1	1	1
WTE	0.143	3	0.2	0.25	2	1	1	1

Annex table 22 :Pairwise comparison matrix of alternatives with respect to employment creation subcriteria

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	6	0.25	6	6	6	6	6
CSP	0.167	1	0.111	1	1	1	1	1
SWH	4	9	1	9	9	9	9	9
Wind	0.167	1	0.111	1	1	1	1	1
Geothermal	0.167	1	0.111	1	1	1	1	1
Biomass	0.167	1	0.111	1	1	1	1	1
Biogas	0.167	1	0.111	1	1	1	1	1
WTE	0.167	1	0.111	1	1	1	1	1

Annex table 23 :Pairwise comparison matrix of alternatives with respect to acceptability of local residents' subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	1	0.111	1	1	0.111	1	1
CSP	1	1	0.111	1	1	0.111	1	1
SWH	9	9	1	9	9	1	9	9
Wind	1	1	0.111	1	1	0.111	1	1
Geothermal	1	1	0.111	1	1	0.111	1	1
Biomass	9	9	1	9	9	1	9	9
Biogas	1	1	0.111	1	1	0.111	1	1
WTE	1	1	0.111	1	1	0.111	1	1

Annex table 24: Pairwise comparison matrix of alternatives with respect to national energy security subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	3	2	4	4	3	3	2
CSP	0.333	1	0.500	2	2	1	1	0.5
SWH	0.5	2	1	3	3	2	2	1
Wind	0.250	0.5	0.333	1	1	0.5	0.5	0.333
Geothermal	0.250	0.5	0.333	1	1	0.5	0.5	0.333
Biomass	0.333	1	0.5	2	2	1	1	0.5
Biogas	0.333	1	0.5	2	2	1	1	0.5
WTE	0.5	2	1	3	3	2	2	1

Annex table 25: Pairwise comparison matrix of alternatives with respect to CO2 emissions subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	1	1	1	1	9	7zX	4
CSP	1	1	1	1	1	9	7	4
SWH	1	1	1	1	1	9	7	4
Wind	1	1	1	1	1	9	7	4
Geothermal	1	1	1	1	1	9	7	4
Biomass	0.111	0.111	0.111	0.111	0.111	1	0.333	0.167
Biogas	0.143	0.143	0.143	0.143	0.143	3	1	0.25
WTE	0.250	0.250	0.250	0.250	0.250	6	4	1

Annex table 26 :Pairwise comparison matrix of alternatives with respect to land and water requirements subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	1	0.5	1	1	8	8	1
CSP	1	1	0.5	1	1	8	8	1
SWH	2	2	1	2	2	9	9	2
Wind	1	1	0.5	1	1	8	8	1
Geothermal	1	1	0.5	1	1	8	8	1
Biomass	0.125	0.125	0.111	0.125	0.125	1	1	0.125
Biogas	0.125	0.125	0.111	0.125	0.125	1	1	0.125
WTE	1	1	0.5	1	1	8	8	1

Annex table 27: Pairwise comparison matrix of alternatives with respect to visual impact subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	3	2	4	4	4	3	3
CSP	0.333	1	0.5	2	2	2	1	1
SWH	0.5	2	1	3	3	3	2	2
Wind	0.25	0.5	0.333	1	1	1	0.5	0.5
Geothermal	0.25	0.5	0.333	1	1	1	0.5	0.5
Biomass	0.25	0.5	0.333	1	1	1	0.5	0.5
Biogas	0.333	1	0.5	2	2	2	1	1
WTE	0.333	1	0.5	2	2	2	1	1

Annex table 28: Pairwise comparison matrix of alternatives with respect to armed conflict subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	1	0.5	1	1	1	1	0.5
CSP	1	1	0.5	1	1	1	1	0.5
SWH	2	2	1	2	2	2	2	1
Wind	1	1	0.5	1	1	1	1	0.5
Geothermal	1	1	0.5	1	1	1	1	0.5
Biomass	1	1	0.5	1	1	1	1	0.5
Biogas	1	1	0.5	1	1	1	1	0.5
WTE	2	2	1	2	2	2	2	1

Annex table 29: Pairwise comparison matrix of alternatives with respect to investment risk subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	3	2	5	5	4	4	3
CSP	0.333	1	0.5	3	3	2	2	1
SWH	0.5	2	1	4	4	3	3	2
Wind	0.2	0.333	0.25	1	1	0.5	0.5	0.333
Geothermal	0.2	0.333	0.25	1	1	0.5	0.5	0.333
Biomass	0.25	0.5	0.333	2	2	1	1	0.5
Biogas	0.25	0.5	0.333	2	2	1	1	0.5
WTE	0.333	1	0.5	3	3	2	2	1

Annex table 30: Pairwise comparison matrix of alternatives with respect to land political categorization (A, B, C) subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	3	0.5	3	3	2	3	2
CSP	0.333	1	0.25	1	1	0.5	1	0.5
SWH	2	4	1	4	4	3	4	3
Wind	0.333	1	0.25	1	1	0.5	1	0.5
Geothermal	0.333	1	0.25	1	1	0.5	1	0.5
Biomass	0.5	2	0.333	2	2	1	2	1
Biogas	0.333	1	0.25	1	1	0.5	1	0.5
WTE	0.5	2	0.333	2	2	1	2	1

Annex table 31: Pairwise comparison matrix of alternatives with respect local legal framework maturity subcriteria.

Renewable energy technologies	Solar PV	CSP	SWH	Wind	Geothermal	Biomass	Biogas	WTE
Solar PV	1	4	2	4	5	4	4	4
CSP	0.25	1	0.333	1	2	1	1	1
SWH	0.5	3	1	3	4	3	3	3
Wind	0.25	1	0.333	1	2	1	1	1
Geothermal	0.2	0.500	0.25	0.5	1	0.5	0.5	0.5
Biomass	0.25	1	0.333	1	2	1	1	1
Biogas	0.250	1	0.333	1	2	1	1	1
WTE	0.250	1	0.333	1	2	1	1	1

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ب

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د. يحيى صالح

الملخص

حاليًا، أكثر من 90% من الكهرباء المستخدمة في الأراضي الفلسطينية تعتمد على الصادرات. هذا الاعتماد لفترات طويلة من الزمن ليس خيارًا آمنًا ومناسبًا. ولكن، هناك العديد من تقنيات الطاقة المتجددة التي يمكن استخدامها كحل لنقص الكهرباء ولإمدادات الطاقة في المستقبل؛ لكن عملية تنويع مصادر الطاقة هي مهمة معقدة وذلك لتداخل العديد من العناصر في هذه العملية. استخدمت هذه الدراسة نهج قرار متعدد المعايير (MCDM) يعتمد على أسلوب التحليل الهرمي (AHP) لاختيار وترتيب ثمانية بدائل للطاقة المتجددة في الأراضي الفلسطينية، وهي: الطاقة الشمسية الكهروضوئية (PV)، سخانات المياه الشمسية (SWH)، الطاقة الشمسية المركزة (CSP)، طاقة الرياح، الطاقة الحرارية الأرضية، الكتلة الحيوية، الغاز الحيوي، وكذلك تقنية تحويل النفايات إلى طاقة (WTE). في هذه الدراسة، تم استخدام نموذج AHP لأول مرة في تخطيط الطاقة في السياق الفلسطيني. تم وضع المجموعة النهائية من المعايير الرئيسية والمعايير الفرعية بناءً على رأي الخبراء في هذا المجال، بالإضافة إلى المراجعة الأدبية للدراسات المتعلقة بتخطيط الطاقة باستخدام الأدوات التي تعتمد على نهج القرار متعدد المعايير. يتكون نموذج التقييم الخاص بأسلوب التحليل الهرمي من خمسة معايير رئيسية واثنين وعشرين معيارًا فرعيًا، بالإضافة إلى ثمانية بدائل مختلفة للطاقة المتجددة. يمكن تصنيف المعايير المستخدمة ضمن الفئات التالية: تقنية، اقتصادية، اجتماعية-سياسية، بيئية، ومخاطر. كشفت نتائج الدراسة أن تقنية السخانات الشمسية هي الطاقة المتجددة الواعدة، تليها الطاقة الشمسية الكهروضوئية، الطاقة الحرارية الأرضية، الرياح، تقنية تحويل النفايات إلى طاقة، الغاز الحيوي، الكتلة الحيوية، وأخيرًا الطاقة

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الشمسية المركزة. يقوم النموذج أيضًا بتحليل أداء كل بديل من بدائل الطاقة بالنسبة لتغيير الأوزان الخاصة بالمعايير الفرعية والرئيسية. علاوة على ذلك، يوضح النموذج كيف يميل كل بديل نحو معيار معين. في هذه الدراسة، تم إجراء تحليل الحساسية لإظهار كيف يتغير السلوك والتصنيفات الإجمالية للبدائل فيما يتعلق بتغيير الأوزان بالنسبة للمعايير الرئيسية والفرعية. إلى جانب تحديد الأولويات وترتيب البدائل المختلفة، يمكن استخدام نتائج النموذج المقترح لوضع خطة طويلة الأمد فيما يخص نظام الطاقة وبما يحقق أهداف الاستدامة.

