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OPTIMAL SITE SELECTION FOR COMBINED RENEWABLE ENERGY INSTALLATIONS IN LEBANON

by
NOUR HASSAN BAALBAKI

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by

NOUR HASSAN BAALBAKI

Approved by:

[Dr. Ali Bazzi, associate professor] Advisor
[Department of Electrical and Computer Engineering]

[Dr. Nesreene Ghaddar, professor] Member of Committee
[Maroun Semaan Faculty of Engineering and Architecture-Dean's office]

[Dr. Ibrahim Alameddine, assistant professor] Member of Committee
[Department of Civil and Environmental Engineering]

Date of thesis/dissertation defense: [January, 2020]

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AN ABSTRACT OF THE THESIS OF

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In our modern time, energy has enhanced the quality of life as well as economic development. The energy consumed is mostly from fossils fuels that are limited in nature and have drastic impacts on the environment. In search for a cleaner and a more sustainable energy resource, while maintaining similar human and economic development, renewable energy resources have become the alternative. At times, however, the deployment of such renewable energy technologies could be a challenging decision for many developing countries; renewable energy projects can either be a success or a failure. Additionally, since each type of renewable energy resource has its advantages and disadvantages, the most appropriate resource among them must be selected in order to gain its optimal benefits.

The purpose of this research is to present a methodology to identify and prioritize the potential renewable energy development site using Analytical Hierarchy Process (AHP) and Geographical Information Systems (GIS) in the context of Lebanon. A series of maps has been created to illustrate possible locations for renewable energy power plants. Convenient site selection criteria have been identified according to the resources, topography, environment, and economics, then weighed using AHP method. A map of resources was generated by overlaying available solar energy, wind energy, biomass energy, and geothermal potential maps using the spatial analysis tool in a GIS environment. While geothermal and biomass results are just illustrative, results show highly, moderately, and least suitable sites to prioritize the decision of renewable energy development all over Lebanon, but the proposed methodology could be extended to different contexts for similar purposes. As a result, the total potential of annual generation was calculated in different areas based on available energy resources. A map of Lebanon has been generated as an open platform for students to advance their knowledge and extend their research, and for companies and government agencies to invest in potential projects.

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CHAPTER I

INTRODUCTION

A. Towards Renewable Energy Resources

Access to energy is essential for human wellbeing, economic development, and poverty alleviation. Ensuring that everyone has sufficient access to energy is an ongoing and pressing challenge for global development. In the twentieth century, there was a “twentyfold increase” in the use of fossil fuel.

With growing concerns about greenhouse gas emissions, the security of conventional energy supplies, and the environmental safety of conventional energy production techniques, renewable energy systems are becoming increasingly important and are receiving attention worldwide. In fact, renewable energy sources have drawn increased attention as a result of limited supply of fossil fuels and environmental concerns. They are crucial part of reducing greenhouse gases that cause climate change and polluting emissions. Therefore, many countries have switched to renewable energy sources as part of their economic strategy.

B. Problem Statement

Renewable energy projects are more challenging compared to conventional energy projects. There are plenty of barriers when implementing a renewable energy project, which has caused several renewable energy projects to be canceled during the past few years. For instance, PV-tech (2016) reported a massive cancellation of future renewable energy projects in Brazil due to decreased electricity demand, largely driven by decreased GDP. In California, USA, Travis Air Force Base (2010) reported a cancelation of a potential solar PV project due to existing land users and social impact. In Ontario, Canada, plenty of sources report on the recent cancellation of a wind turbine project. Different reasons were cited; some reasons were related to health and the environmental impacts on neighbors while others were due to electricity prices. In addition, some projects were cancelled due to land availability, poor site access, and availability of transmission lines.

On the other hand, Jacobson reported a potential loss of 3.9 million jobs in the conventional energy sector. However, he implied that there will be creation of new jobs in the long term [1].

Thus, approving complex utility-scale renewable energy projects can be challenging, where many factors beyond technical ones should be taken into consideration. These factors include promise of job creation, societal acceptance, environmental considerations, and local market characteristics. In general, a piece of land should be used in terms of its capacity to meet human needs and to ensure the sustainability of existing ecosystems, so the fundamental principle of sustainability is to ensure the most suitable land use considering the properties of the land and needs of the users. This needs a suitability analysis which includes a decision-making process that takes into consideration a broad range of factors. Prioritizing these factors is difficult in order to select the suitable land use.

Therefore, implementing renewable energy projects requires analysis of suitable locations by taking into consideration different factors pertaining to the chosen renewable energy technology.

C. Thesis Statement

Electricity is essential for Lebanon; a country suffering greatly from the shortage in its electricity production, which is partially compensated for by the use of polluting private diesel generators. Lebanon suffers from insecure energy supply marked by a growing deficit in energy balance, significant supply-demand imbalance, high generation costs, and lack of financial sustainability. Power cuts and the use of private generators are hindering the progress of Lebanon and Lebanese economy, and lowering the quality of life of people living in this country. Lebanon is chosen to be our case study for this thesis.

A major challenge lies in whether or not Lebanon can switch to renewable energy sources (RESs). In fact, Lebanon has several competitive advantages that will facilitate the development of a renewable energy industry. The first of these is the compatibility with the physical requirements for RES performance. Solar radiation is plentiful, while wind, water, and some biological resources are available - despite restraining factors of limited availability of land and space.

By considering all the available renewable energy resources, a sustainable energy plan must be set by choosing the best energy resources to be exploited in different locations all over Lebanon. This will lead to a new methodology to optimally select renewable energy installation locations and allocate investments.

The vision:

"In a country with consistent power shortages, renewable energy might be the ticket to reduce public debt, and increase the ability to produce electrical power needed as a nation."

CHAPTER II

LITERATURE REVIEW

The literature review is divided into three main sub-sections:

1- Overview of the electrical energy sector in Lebanon
2- Renewable energy resources in Lebanon
3- Review of site selection criteria
4- Review of MCDM methods

A. Literature Review of the Energy Sector in Lebanon

Over the past four decades, the energy sector in Lebanon has been going through a rough patch; making it amongst the worst sectors, internationally, to satisfy consumers' demands. The demand is met currently by importing fuel products from abroad that is around 7.3 Mtoe (2013), while 47% of Total Primary Energy Supply (TPES) imports, mainly oil, are used to supply the electrical power plants [2].

To add on, the generation, transmission, and distribution of electricity in Lebanon is monopolized and owned by a public institution, Electricity of Lebanon (EDL), which is incapable of supplying the electricity demanded by households on a consistent and reliable basis. Many Lebanese regions are suffering from severe outages and power cutoff sessions; the sessions can reach 18 hours in some areas. This electric instability is ongoing due to a continuous increase in demand and perpetual decay of the existing power plants. It is noteworthy of mentioning that this sector in Lebanon is capturing around one fifth of the public expenditure while holding a sterile development state.

The generation network is composed of 7 major power plants. On one hand, Zouk, Jieh and Al Hrayshe power plants operate on heavy fuel oil (HFO) from fired steam turbines. On the other hand, Deir Ammar and Zahrani power plants operate on natural gas, while those of Tyre and Baalbeck function on diesel fired open cycle gas turbines. However, none of these plants function on natural gas (NG) - diesel oil (DO) is used instead. The operational cost of the power plants is high since the installed power plants feed on diesel oil and heavy fuel oil which are of high cost worldwide. In addition, the power plants are degenerating and their efficiency is decreasing; only 72.5% of the total power plants are operating since 2018 [2]. Consequently, private generators bridge the gap between the supply and demand of electricity since the early 1990s even though there is no legal framework regulating this business.

Many reasons are contributing to the drop of the electricity supply provided by these plants and to the inefficient use of electricity generated. First, plants decay and the absence of systematic plant rehabilitation are resulting perpetually and negatively in their generating capacity. Plants are becoming less efficient due to the insufficient and inconsistent maintenance as well as the unreliable asset.

For example, the non-rehabilitated plants of Zouk and Jieh are suffering from a deviation in their efficiency in terms of fuel/KWh generated, and this deviation is measured to be around 15% to 25% less than the original design of the plants. The maintenance of the existing power plant would have increase the operated capacity [3]. Rehabilitating and upgrading existing plants may be a worthy opportunity to meet a part of the growing demand, whereas neglecting the prevailing progressive decay would have economic aftermaths due to the scarce resources and inefficient generation processes. The plant rehabilitation and upgrade has the ability to shift the existing plant capacity to start at 245MW [3].

The volume of electricity supplied in Lebanon is estimated to diminish 3% on a yearly basis due to plants decay at times where the demand of electricity is increasing by 7% on a yearly basis [3].This perpetual increase in electricity demanded and progressive drop in electricity supplied will upshot a widening gap; that have resulted in an electricity deficit of around 70% in year 2015 [3].

Taking into account the pollution resulting from conventional sources of energy, the alternative sources of energy, also called renewable energy (RE) are proving to be the best option to obtain clean energy.

There are various types of renewable sources of energy and each has been proven to be successful in a certain domain and in a certain place. Although different alternative sources could be used, the two types that most experts agree on their special applicability in Lebanon are: solar and wind energy. Lebanon's geographical location gives this country a very good global solar radiation and wind speed compared to other countries in Europe [4].

B. Renewable Energy Resources in Lebanon

In recent years, Lebanon has witnessed an accelerated integration of renewable energy into its electricity mix [5]. In line with this transition, Lebanon has decided to embark on an energy diversification action plan; based on promoting renewable energy development and energy efficiency. The National Renewable Energy Action Plan (NREAP) for 2016-2020 defines the country's target to implement RE projects equivalent to 12% of the projected total electricity and heating demands. In addition, Lebanon has recently extended these projections to allow the country to meet 30% of the total electricity and heat from renewables by 2030.

In fact, renewable energy holds strong potential in Lebanon, targeting 450 MW in wind energy and 300 MW in solar PV, based on the 2030 vision in Lebanon's NREAP [6]. Renewable energy has the opportunity to contribute positively to Lebanon's power sector; thus, increasing the reliability of the power supply, decreasing the country's dependence on fuel imports, improving the affordability of the energy mix, and reducing the need for subsidies to EDL.

In January 2017, the MoEW Lebanese Center for Energy Conservation (LCEC) released Lebanon's NREAP 2016-2020. Its primary purpose is to further break down the legally-binding target of 12% renewable energy by the year 2020. The NREAP outlines a vision for a tangible RE target of 12.6% by the year 2030, considering that Lebanon's total energy demand for heat and power is expected to double between 2015 and 2030.

Onshore wind farms and solar photovoltaic (PV) plants are considered the key installations for achieving both the 2020 target and the 2030 vision. In absolute numbers, 200 MW of wind energy and 150 MW of solar PV is targeted by 2020, whereas 450 MW of wind energy and 300 MW of solar PV plants are expected to be operating in Lebanon by 2030.

However, renewable energy resources—such as solar energy, wind energy, micro-hydro energy, and biomass—may be available in significant quantities but are not easily accessible in terms of harvesting or harnessing them, particularly in remote areas. The limited accessibility is not only due to economics alone but also to geographical restriction. For instance, in order to build a wind turbine on a hilltop with almost no road access to the installation site is quite challenging. Hence, availability and accessibility are two different aspects when identifying workable renewable energy systems in Lebanon.

C. Review of Site Selection Criteria

One of the main objectives in renewable energy plant site selection is finding the most appropriate site with desired conditions as per the selection criteria. A criterion is a measurable facet of judgment which makes it possible to illustrate and enumerate alternatives in a decision. So, the determination of suitable locations for a power plant depends on the complete and accurate understanding of those criteria and how to choose them. With the inputs from various works and research studies, several criteria were identified and selected for the different renewable energy technologies. These criteria were set based on technical, economic, social, and environmental factors, and by their measurement on continuous-scale indicators; defined as magnitudes that measure or rate a factor.

In general, the site selection process must consider decision criteria as well as restriction factors that need to be assessed owing to their positive or negative impacts on the performance and cost of the electricity generated. Moreover, knowing the potential sites is a strategic primarily milestone for annual power plant output prediction as well as financial viability.

To deploy a solar or a wind project on a utility-scale, several criteria and factors should be considered with the aim of optimizing the location which will result in a more efficient system to supply the needed consumers and less negative impact on the environment.

For the different renewable energy technologies, site selection criteria were selected from literature reviews and described below.

1. Wind Energy Technology

a. Definition

Wind energy conversion refers to the process of creating electricity using the wind or air flows that occur naturally in the earth's atmosphere. Wind turbines are used to capture kinetic energy from the wind and generate electricity.
Wind farms can be based onshore (on land) or offshore (sea or freshwater):
Offshore wind farms are different from onshore wind farms in many aspects; the latter are cheaper.

b. Site Selection Criteria for Wind Energy Technology

Among different criteria, the selection of a site is the first step for the wind farm developers. Various techniques are used for site identification of onshore/offshore/land-based wind farms. It includes installation of a wind mast for several months/years and recording of relevant data. Another method is the use of Geographic Information System (GIS) for data collection and analysis purpose. GIS has been designed to be as flexible as possible, allowing the user to specify which criteria will be used for the site selection, and if included, which buffer distances to use around each excluded feature. The criteria include various parameters and exclusion factors such as: wind speed information, elevation, slope, highways and railways, built-up area, forest zone, and scenic area.

The site selected for wind farm development needs to have many positive attributes including:

Criterion 1: Wind resources

The wind resource is a very important economic criterion that affects the establishment of a wind farm in any location.

The wind energy resource assessment is key to wind power projects site selection. It refers to the wind resources that enable high performance while not damaging wind turbines. The sub-criteria are mainly considered from two aspects: available wind resources and adverse influences of energy resources on plants operation and power generation.

Wind energy available at any location is measured by a quantity known as Wind Power Density (WPD). It is determined by calculating the average annual power available per square meter of the swept area of a turbine and is tabulated for different heights above ground. The calculated WPD are included in an index developed by the National Renewable Energy Laboratory (NREL) and referred to as "NREL CLASS". The larger the WPD calculation, the higher the rating by its class.

The wind power density calculation also includes the effect of wind velocity and air density.

Table 1. Wind power classification

Wind Power Class	At a height of 10 meters		At a height of 50 meters		Resource Potential
	Wind Power Density (W/m^2)	Speed (m/s)	Wind Power Density (W/m^2)	Speed (m/s)	
1	0 – 100	0 – 4.4	0 – 200	0 – 5.6	Poor
2	100 - 150	4.4 – 5.1	200 – 300	5.6 – 6.4	Poor
3	150 - 200	5.1 – 5.6	300 – 400	6.4 – 7.0	Fair
4	200 - 250	5.6 – 6.0	400 – 500	7.0 – 7.5	Good
5	250 - 300	6.0 – 6.4	500 – 600	7.5 – 8.0	Excellent
6	300 - 400	6.4 – 7.0	600 – 800	8.0 – 8.8	Outstanding
7	400 - 1000	7.0 – 9.4	800 - 2000	8.8 – 11.9	Superb

Note that the values of wind speed at different heights are calculated based on the annual average wind speed and the wind shear index (1/7).

The sub-criteria needed and their definition:

- *Wind speed*: or wind flow velocity, is a fundamental atmospheric quantity caused by air moving from high to low pressure; usually due to changes in temperature.
- Wind power density: Including the effect of wind speed and wind speed distribution on the air density, wind power density is a composite indicator to evaluate the wind energy resources. The calculation formula of wind power density is:

$$D_{wp} = \frac{1}{2}\sum_{i=1}^{n} \rho v_i^3$$

Where:
n refers to the records number in a set period.
ρ represents the air density(kg/m^3).
$v^3{}_i$ stands for the cubic meters of wind speed (m/s) in the ith record.

- *Wind direction and wind frequency:* The arrangement of the generator sets location in wind farms depends on the distribution of wind power density direction and topographical features. To show the information about the distributions of wind speeds, and the frequency of the varying wind directions, a diagram can be drawn, the wind rose diagram. It display wind speed and wind direction at a particular location over a period of time. This is a qualitative indicator which could use the integers from 1 to 5 as the value of different quantitative ranks.
- *Turbulence intensity:* Measures ratio of the standard deviation of the wind speed (m/s) to the average wind speed during a period of 10 min (m/s). It determines the fatigue load of the wind turbine and

largely affects the service life of the units. This criterion applies the integrated turbulence above 30 m, which is evaluated by the dominant wind turbulence intensity and partial sector turbulence intensity.

The formula of turbulence intensity is as follows:

$$I_T = \frac{б}{V}$$

Where:

б stands for the standard deviations of wind speed (m/s) and

V stands for the average wind speed (m/s).

Turbulence characteristics of wind farms are very important, which may have an adverse effect on wind turbine performance, such as reducing power output and leading to extreme loads, and eventually undercutting and destroying wind power generators.

Other definition:

- *Wind shear index:* sometimes referred to as wind gradient, is a difference in wind speed or direction over a relatively short distance in the atmosphere. It refers to the variation of wind over either horizontal or vertical distances.
- *Weibull:* Naturally, the wind's speed constantly varies. In order to be able to predict a wind turbine's production, it is necessary to know exactly the frequency and strength of wind blow. Normally, the wind is measured with an anemometer and the mean wind speed is recorded every 10 minutes. This data can be sorted into wind speed classes of 1 m/s each. The energy contained in the wind at a certain site may then be expressed by this frequency distribution.
  The Weibull distribution is often a good approximation for the wind speed distribution:

$$f(v) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} e^{-\left(\frac{v}{A}\right)^{k}}$$

Where:

A is the Weibull scale parameter in m/s, a measure for the characteristic wind speed of the distribution. *A* is proportional to the mean wind speed.

k is the Weibull form parameter. It specifies the shape of a Weibull distribution and takes on a value of between 1 and 3. A small value for *k* signifies very variable winds, while constant winds are characterized by a larger *k*.

Criterion 2: Accessibility

Accessibility is a vital requirement in order to reduce the cost of infrastructural development and maintenance. As such, proximity to the existing grid and road system is prioritized to achieve lower transmission losses and ease of access to the plant for activities and operation throughout the expected life of the system.

The sub-criteria needed and their definition:

- *Proximity to roads:* The site should be accessible by roads for the transportation of the system components, construction materials, and other equipment (for onshore installations).
- *Proximity to transmission lines:* A critical issue in keeping costs down in building a wind farm is minimizing the amount of transmission infrastructure that has to be installed. High voltage lines can cost thousands of dollars per mile. Whenever possible, availability and access to existing lines should be considered while selecting a site. Wind farms are generally connected to the 33-66kV electricity distribution grid. The cost of this connection can have a significant bearing on economic viability, and the distance from the wind farm to the grid can have a significant impact on the connection cost.
- *Distance to shore:* Distance from the shore will influence the maintenance, transportation, and installation costs (for marine installations). Different from the distance from the channel and anchorage, the farther the distance from shore, the worse the alternative is.

Criterion 3: Population Center

Energy produced from an energy farm located near high population densities has a shorter distance to travel and will rely on fewer transmission lines to transfer the energy; thus, reducing the cost of supplying the energy to consumers.

The sub-criteria needed and their definition:

- *Proximity to urban areas:* With respect to the distance to urban areas, certain studies consider locations that are far away from cities to be more suitable for renewable energy development; hence, avoiding negative environmental impact on urban development as well as the Not In My Backyard (NIMBY) opposition. On the other hand, other studies indicate that sites near cities have more economic advantages - minimizing the distance electricity would have to travel and reducing associated line-loss and transmission expenses.
- *Distance to rural communities:* Renewable energy is considered as a potentially significant new source of: career opportunities, rural growth in rural areas, and means of addressing environmental and energy security concerns. While RE indeed represents an opportunity for stimulating economic growth in hosting communities, it also requires a complex and flexible policy framework and a long-term strategy. Making a positive connection between RE development and local economic growth will require more coherent strategies, the

right set of local conditions, and a place-based approach to deployment.

- *Population density:* locating the power plants nearby the adequate consumer is a key factor that should be taken into account. Establishing a farm near the highly populated cities is an advantage.

Criterion 4: Topology

It is important to understand the topographical features (elevation, slope, and aspect) of the study area, which will assist in proper economic energy planning and better decision making for system deployment.

The sub-criteria needed and their definition:

- *Slope:* Steep slopes make construction difficult and more expensive. With the increase of the slope, the complexity of the design increases; hence, leading to a proportional increase in costs.

- *Elevation:* Elevation is one of the effective factors in industrial location. It has a regression correlation with coefficient of 95% with temperature and precipitation. The height of the region from sea level is inversely proportional to atmosphere thickness. Thick atmosphere implies more concentration of the compounds, absorption, or reflection factors. Since the coarser and thicker materials are collected in the lower classes, the atmosphere is thinner on the tops of the mountains. The atmosphere thickness and compounds control surge power in addition to short wave energy of the sun. Therefore, high lands have more potential than low lands because they receive higher solar energy. However, high altitude areas have higher transportation cost and are not preferable.

Other criteria:

- *Land ownership:* Landowners, both private and public, will expect to be compensated for any wind energy development that occurs on their land. Royalty or lease agreements will need to be discussed with all parties involved. Roads, transmission equipment, maintenance infrastructure, turbines along with others need to be considered. Moreover, the construction of a wind farm necessitates the use of heavy industrial equipment. Consequently, developers will need to invest in roads capable of accommodating significant weight. To do so, this requires the cooperation of landowners and, in some cases, the local community.

- *Foundation:* Wind-turbine foundation design requires appropriate geotechnical studies namely, knowledge of loads and correct estimates of stresses and settlement; those must be calculated in geotechnical engineering studies. Geotechnical studies must also be conducted to assess soil properties for a given site with reference to locally available construction standards and regulations. Additionally, the foundation system includes the upper part of the base that links the tower to the foundation elements transferring loads to the soil. An effective design requires a solid knowledge of the soil characteristics of the site.
  Wind turbine foundation design should enable the structure to withstand vertical, horizontal, static and transient stresses resulting from the wind turbine itself and its operation, wind conditions, and potential earthquakes.
- *Land use and land cover:* Land use is the main basis and the most influential criteria for urban-rural planning and the distribution of various land-use types leads to considerable constraints in urban and rural planning. Certain land use types have restricted use. These areas may not be used because of economic and environmental interests. Land cover represents all the physical and biological material on the Earth's surface that make an area favorable or not for the installation of a power plant.
- *Noise:* Noise from wind turbines comes primarily from the rotor blades as they slice through the air. Although wind machines built recently make substantially less noise than earlier models, noise from wind machines is potentially a problem if wind farms are sited too close to residences.
- *Bird strikes:* Birds can fly into fast-moving rotor blades of wind machines and be killed. While evidence to date indicates that birds generally learn to avoid the spinning rotors, some problems with bird strikes have been noted.
- *Visual impacts:* The presence of wind turbines produce changes in views and skylines, and thus have a visual impact on the area in which they are cited. Visual impacts may be an especially important consideration if the turbines are to be located in pristine or wild areas. The access roads and power lines needed for grid-connected turbines can cause additional aesthetic impacts.
- *Water depth:* Water depth is a distinguishing factor for the site selection of offshore wind farm owing to the offshore nature, and this factor will have an impact on the installation of the wind turbine and finally influence the cost of installation. It is very hard to install the wind turbine in the site with large water depth.

- *Distance to shore and waterways:* The offshore wind farm located close to the shore especially in busy waterways may have significant impact on the maritime safety.
  Maritime safety is the key issue for offshore wind farm in the busy waterway. As there are many ships navigating, anchoring or fishing in the nearby waterways, the construction of offshore wind farm will occupy the navigable waterways and also have impact on the radar with very high frequency; as a result, this will interrupt the communication of collision avoidance for the ships. Moreover, the distance from the shore will have impact on the electric and grid connection.

2. Solar Energy Technology

a. Definition

Compared to other renewable energy sources, solar energy is a low-density power supply that necessitates vast areas for exploitation. In fact, energy can be harnessed directly from the sun, even in cloudy weather. Solar energy is used worldwide and is increasingly popular for generating electricity. Solar power is generated in two main ways:

- Photovoltaics (PV), also called solar cells, are electronic devices that convert sunlight directly into electricity. Solar PV installations can be combined to provide electricity on a commercial scale, or arranged in smaller configurations for mini-grids or personal use. Solar PV systems can be operated in OFF or ON grid connection.
- Concentrated solar power (CSP), uses mirrors to concentrate solar rays. These rays heat fluid, which creates steam to drive a turbine and generate electricity. CSP is used to generate electricity in large-scale power plants.

Selecting a suitable site is a crucial step toward developing a feasible utility-scale solar PV project. Throughout solar energy research, a common question exists: What is the optimal site for utility-size solar PV? Performing a comprehensive solar site analysis is the first step toward ensuring a cost-effective and well-performing solar project.

b. Site Selection Criteria for Solar Energy Technology

In general, the process must consider decision criteria as well as restriction factors that need to be assessed owing to their positive or negative impacts on the performance and cost of the electricity generated. Moreover, knowing the potential sites is a strategic primarily milestone for annual power plant output prediction as well as financial viability.

To deploy a solar project on a utility-scale, several criteria and factors should be considered with the aim of optimizing the location which will result in more efficient system, more economic to supply the needed customers and less impact on the environment.

Most solar site suitability studies deliberate solar irradiation as the most important decision criteria.

Criterion 1: Solar resources

Significant indicator of judging renewable sources to be utilized in sizable scales includes good availability of resources. Solar energy is radiant energy produced by the sun. In many parts of the world, direct solar radiation is considered to be one of the best prospective sources of energy.

The sub-criteria needed and their definition:

- *Solar irradiation:* is an essential criterion for large-scale PV solar power projects. Considerable amounts of solar energy play a significant role in producing more electrical power from available resources.

Furthermore, the solar irradiation is composed of three components, the global (GHI), the diffuse (DHI) and the direct (DNI). Each component is used for a specific solar technology. As for concentrating solar power (CSP) plants, the DNI has to be assessed since it can be concentrated, while for the PV, we have to assess and map the amount of the GHI.

- *Air temperature:* Air temperature plays a vital role in PV system performance. As the surrounding air cools, PV modules and inverters convectively; hence, improving the PV system efficiency.

Criterion 2: Accessibility

Accessibility is a vital requirement in reducing the cost of infrastructural development and maintenance. As such, proximity to the existing grid and road system is prioritized to achieve lower transmission losses and ease of access to the plant for activities and operation throughout the expected life of the system.

The sub-criteria needed and their definition:

- *Proximity to roads:* Because roads are expensive to build, selecting sites closer to roads is cheaper and minimizes the environmental impacts associated with building new roads. The existing road network must be suitable for the transportation of materials needed for the construction of solar power plant. Also, potentially suitable land should have roads about 3 meters wide for the appropriate maintenance of the farm. PV systems could be integrated into infrastructure such as noise barriers along roads. Accessibility to site from highways as it affects the transportation cost and thus the initial cost.

- *Proximity to transmission lines:* Proximity to power lines and substations prompts adequate accessibility to the grid and aids in avoiding the high cost of establishing new lines as well as minimizing power loss in the transmission.
- *Distance to shore:* Distance from the shore will influence the maintenance, transportation, and installation costs. Also a convenient distance from a shoreline could protect a solar farm from consequences of natural sea disasters.

Criterion 3: Population Center

Energy produced from an energy farm located near high population densities will have a shorter distance to travel and will depend on fewer transmission lines to transfer the energy; thus, reducing the cost of supplying the energy to consumers.

The sub-criteria needed and their definition:

- *Proximity to urban areas:* With respect to the distance to urban areas, certain studies consider locations that are far away from cities to be more suitable for renewable energy development; hence, avoiding negative environmental impact on urban development as well as the Not In My Backyard (NIMBY) opposition. On the other hand, other studies indicate that sites near cities have more economic advantages - minimizing the distance electricity would have to travel and reducing associated line-loss and transmission expenses.
- *Distance to rural communities:* Renewable energy is considered as a potentially significant new source of: career opportunities, rural growth in rural areas, and means of addressing environmental and energy security concerns. While RE indeed represents an opportunity for stimulating economic growth in hosting communities, it also requires a complex and flexible policy framework and a long-term strategy. Making a positive connection between RE development and local economic growth will require more coherent strategies, the right set of local conditions, and a place-based approach to deployment.
- *Population density:* locating the power plants nearby the adequate consumer is a key factor that should be taken into account. Establishing a farm near the highly populated cities is an advantage.

Criterion 4: Topology

It is important to understand the topographical features (elevation, slope, and aspect) of the study area, which will assist in proper economic energy planning and better decision making for system deployment.

The sub-criteria needed and their definition:

- *Slope:* the flat terrain is essential for large-scale PV farms so high slope areas are impractical for such projects due to low economic feasibility. Steep slopes make construction difficult and more expensive. With the increase of the slope, the complexity of the design increases, which often leads to a proportional increase in costs. Installation of photovoltaic panels on steep slopes can cause problems related to erosion, drainage systems, and the stability of the foundation. The slope of the earth's surface affects both conditions of optimal orientation and inclination of PV modules and the technical component of the photovoltaic power plant installation.
  If the slope is small, then the orientation is not important, as it can easily be offset by supporting structures for photovoltaic panels, whereas on steeper slopes, slope orientation is a deterrent, and in this case solar power plant could be built only in the south-oriented areas.
- *Elevation:* high altitude areas have higher transportation cost and are not preferable.
- *Aspect:* It identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors in GIS. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1.

Other criteria:

- *Land ownership and availability of vacant land:* Before the development of a proposed model, it is essential to discuss the issues of land acquisition related to largescale PV projects.
  In fact, land acquisition means compulsory acquisition of land, usually against the willingness of the owner. Land suitability is an essential element of large-scale PV installation; however, suitability does not constitute land availability – it is a scarce resource and acquiring it for large-scale project is a difficult process in any society. The process of land acquisition remains an impediment to

timely implementation of PV installation. Not only does it delay the timely installation, it also increases the cost of installation. In many societies, the unwillingness of land owners to give out their valuable land resources, even when given the high cost of compensation, constitutes a threat to smooth project implementation. So, the availability of land for setting up a solar plant with economies of scale and for future expansion is an important criterion for solar energy deployment.

- *Foundation and soil quality:* Geotechnical studies must also be conducted to assess soil properties for a given site with reference to locally available construction standards and regulations. An effective design requires a very good knowledge of the soil characteristics of the site.
- *Land use and land cover:* Land use is the main basis and the most influential criteria for urban-rural planning, and the distribution of various land-use types leads to considerable constraints in urban and rural planning. Certain land use types have restricted use. These areas may not be used because of economic and environmental interests. Land cover represents all the physical and biological material on the Earth's surface that makes an area favorable or not for the installation of a power plant.
- *Visual impacts:* Visual impacts may be an especially important consideration.
  Visual perception is an important component of environmental quality that can be affected by new structures. The location, design, and/or maintenance of power plant facilities may adversely impact visual features of the landscape.
- *Water availability:* Water resources are also a crucial criterion for site assessment of solar power plants, especially in arid regions where PV panels need to be cleaned in order to keep higher efficiency. CSP needs water for cleaning and cooling.
- *Distance to shore:* Distance from a shoreline could protect a solar farm from consequences of natural sea disasters. Another reason to avoid seaside areas, when installing a solar farm, is their higher price, making such installations less cost-effective.

3. Biomass Energy Technology

a. <u>Definition</u>

The definition of biomass is a renewable energy source from living or recently living plant and animal materials that can be used as fuel. In other words, biomass is plant or animal material used for energy production (electricity or heat), or in various industrial processes as raw material for a range of products [7].

Biomass resources can be grouped into wood residues, generated from wood products industries; agricultural residues, generated by crops, agro-industries and animal farms; energy crops, i.e. crops and trees dedicated to energy production; and municipal solid waste (human waste from sewage plants) [8].

b. Site Selection Criteria for Biomass Energy Technology

Site selection is a complex problem. The location of a biomass plant must satisfy a number of criteria and constraints such as geological and environmental reserve restrictions, which are imposed by several government regulations, limiting the potential location of biomass energy plants.

Most recent studies of biomass plant site selection are under the conditions of the transport distance, acquisition cost, and environmental contamination. The following is a list of site selection criteria for biomass power plant:

Criterion 1: Accessibility

Accessibility is one of the most important factors to be considered in the biomass power plant site selection in order to reduce the cost of infrastructural development and maintenance. As such, proximity to the existing grid and road system is prioritized to achieve lower transmission losses and ease of access to the plant for activities and operation throughout the expected life of the system.

The sub-criteria needed and their definition:

- Proximity to roads: Transportation deals with the movement of biomass between different locations of the network. High transportation cost due to long transportation distances is observed as one of the main contributors for the high biomass logistics cost. Different modes of transportation such as truck, rail and barge are used to transport biomass. Trucks, which are used widely for biomass transportation, are found to be economical only when the transportation distances are short. Rail and barge are considered cost effective for long distance and high volume transportation of biomass. However, the use of these modes may be restricted due to the limited access of biomass supply and demand locations to these modes of transportation.
- Proximity to transmission lines: A critical issue in keeping costs down in building a biomass farm is minimizing the amount of transmission infrastructure that has to be installed.

Criterion 2: Population center

The purpose of building a biomass power plant is to make important contributions to the economic development and people's livelihood of the society.

Social factor has marked effect on our life. The impacts of the biomass power plant on the society specifically includes the following two sub-criteria:

- Promote economic progress of surrounding region: A biomass power plant can provide numerous job opportunities to local people, drive the growth of other related industries (such as logistics), promote regional GDP growth, raise the level of the local per capita income, and improve the quality of life.
- Ease the supply of the demanded electricity: a biomass power plant can effectively alleviate power supply of the local and surrounding areas. Construction scale of a biomass power plant should be based on local and neighboring power demand.

So, the criterion we are looking for is the population density. The population is another attribute to be accounted for, yet the number of households is considered a more suitable parameter since it is reliable indicator of energy consumption.

The sub-criteria needed and their definition:

- *Population density*: locating the power plants nearby the adequate consumer is a key factor that should be taken into account. Establishing a farm near the highly populated cities is an advantage.

Other criteria:

The criteria needed and their definition:

- *Slope*: Steep slopes make construction difficult and more expensive. With the increase of the slope, the complexity of the design increases; hence, leading to a proportional increase in costs.
- *Elevation*: high altitude areas have higher transportation cost and are not preferable.
- *Land use and land cover*: Land use is the main basis and the most influential criteria for urban-rural planning and the distribution of various land-use types leads to considerable constraints in urban and rural planning. Certain land use types have restricted use. These areas may not be used because of economic and environmental interests. Land cover represents all the physical and biological material on the Earth’s surface that makes an area favorable or not for the installation of a power plant.
- *Visual impacts*: The presence of power plants produce changes in views and skylines, and thus have a visual impact on the area in which they are cited. Visual impacts may be an especially important consideration if the turbines are to be located in pristine or wilderness areas. The access roads and power lines needed for grid-connected turbines can cause additional aesthetic impacts.
- *Availability of water*: The presence of large sheets of water will also allow us to choose between the different alternatives.

4. Geothermal Energy Technology

a. Definition

Geothermal energy is the heat from the Earth; it's clean and sustainable. Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma.

Geothermal energy has been widely recognized as an environmentally friendly energy source compared to the fossil fuels. Moreover, geothermal plants can be built much more rapidly than plants using fossil fuel. But any geothermal power plants have some requirements prior to construction; producing electricity with minimum impacts on environment and maximum economic benefits for developers.

b. Site Selection Criteria for Geothermal Energy Technology

Site selection is a complex problem. The location of a geothermal plant must satisfy a number of criteria and constraints such as geological and environmental reserve restrictions that are imposed by several government regulations; hence, limiting the potential location of biomass energy plants.

The main factors determining influence on location of geothermal power plants are: the temperature and the capacity of the source, the depth of resources available and the degree of mineralization of water sources as well as their efficiency. Below is a list of site selection criteria for geothermal power plant:

Criterion 1: Accessibility

Accessibility is one of the most important factors to be considered in the geothermal power plant site selection in order to reduce the cost of infrastructural development and maintenance. As such, proximity to the existing grid and road system is prioritized to achieve lower transmission losses and ease of access to the plant for activities and operation throughout the expected life of the system.

The sub-criteria needed and their definition:

- *Proximity to roads:* One of the important parts of every socioeconomic study is the condition of road network. Access roads are defined as one of the criteria for selecting the appropriate power plant site from two affecting point: economic and environment.
- *Proximity to transmission lines:* A new power plant requires a transmission line which connects the plant to the electricity transmission network. Potential impacts from construction are also of interest to local communities and adjacent landowners. Construction of the required transmission line from a proposed power plant site to the nearest distribution line is one of the factors necessary to take into account in site selection.

Other criteria:

- *Slope:* Slope refers to how steep the surface of the land is. Steep slopes are a limitation for geothermal power plant development, not only because of the cost and transportation, but also water that can find pathway from the drain to flow on the surface.
- *Faults*: In geology, faults are discontinuities (cracks) in the earth's crust that have been responsible for many destructive earthquakes. Geothermal plumbing systems might be controlled by fault planes. Therefore fractures and faults play an important role in geothermal fields, as fluid mostly flows through fractures in the reservoir rocks.
- *Anomaly zone:* Geothermal fluids can be transported economically by pipeline on the Earth's surface only a few tens of kilometers, and thus any generating or direct-use facility must be located at or near the geothermal anomaly zone.
- *Land use and land cover:* Land use is the main basis and the most influential criteria for urban-rural planning and the distribution of various land-use types leads to considerable constraints in urban and rural planning. Certain land use types have restricted use. These areas may not be used because of economic and environmental interests. Land cover represents all the physical and biological material on the Earth’s surface that makes an area either favorable or unfavorable for the installation of a power plant.
- *Visual impacts:* Visual perception is an important component of environmental quality that can be affected by new structures. The location, design, and/or maintenance of power plant facilities may adversely affect visual features of the landscape. Concern over adverse visual impacts can be a source of opposition to the project. In geothermal projects, the visual quality may be deteriorated by loss of naturalness and the imposition of man-made structures such as drill sites, drilling rig, and accessories creating artificial landscape elements in the project area. These are, however, temporary and will be removed when drilling is completed. The power house and related facilities are the main man-made structures – those present in the area for the entire project lifetime, and consideration of its visual impacts are very important. Because natural geothermal manifestations such as hot springs and fumaroles are attractive for tourists, particular attention to the visual effects of a geothermal power plant is necessary.

In conclusion, renewable energy planning has multiple objectives, definitions, and criteria; hence, making it more difficult to attain a system with a perception of sustainability. Thus, an adequate planning system considering necessary political,

social, economic, and environmental aspects is essential to overcome the rising demand for energy with a vision of sustainable development. To solve such complex problems concerning energy planning, multi-criteria decision making (MCDM) is proved to be one of the better tools for efficient energy planning.
In the light of this, the objective is to choose the optimal site location for different renewable energy resources, not just one type of renewable energy system. To attain this objective, a suitable decision rule, which integrated the criteria established in accordance with this objective, was created. This allowed one to assign a weight to each criterion depending on the influence of each on the performance of the future renewable energy installation.

D. Review of the Multi-Criteria Decision Making Methods

In spite of sustainable development, energy planning has become complex due to the involvement of multiple benchmarks including technical, social, economic and environmental ones. This in return puts major constraints for decision makers to optimize energy alternatives independently and discretely especially in the case of rural communities where additional constraints, like culture, play an important role. In addition, topographical limitations concerning renewable energy systems, which are mostly distributed in nature, add to the complexities of energy planning. In such cases, decision analysis plays a vital role in designing such systems by considering various criteria and objectives.

MCDM is a branch of operational research that seeks finding optimal results in complex scenarios including various indicators, conflicting objectives, and criteria. MCDM is booming in the field of energy planning due to the flexibility it provides to decision makers - to take decisions while considering all criteria and objectives simultaneously. MCDM techniques have found wide application in public-sector as well as in private-sector decisions on agriculture resource management, immigration, education, transport, investment, environment, defense, health care, etc. In the recent decade, MCDM has found its grounding application in energy system design.

MCDM has become popular in energy planning as it enables the decision maker to give attention to all the criteria available and make appropriate decision as per the priority. Since a perfect design is governed by multiple dimensions, a good decision maker, in certain situations, may look for the parameters (i.e. technical or economical) that can be compromised. MCDM problems generally comprises of five components which are:

- Goal
- Decision maker's preferences
- Alternatives
- Criteria
- Outcomes

MCDM remains controversial as objectives can lead to different solutions at different times based on the priority set by decision makers or persons involved in the procedure. Moreover, a particular problem can be approached by different methods based on the functions defined. Every method or model has its own drawbacks and restrictions. However, a general procedure of MCDM is illustrated in Figure 1 below.

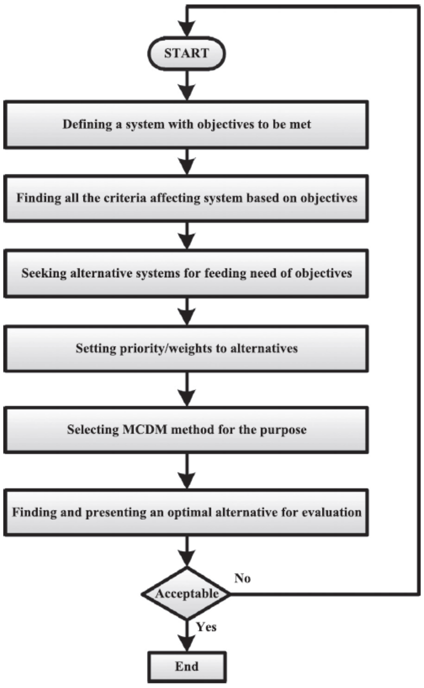


Figure 1. General MCDM procedure

Different MCDM methods were found and these are the popular one, following with a table summarizing their major steps along with their strengths and weaknesses:

a) Weighted Sum Model (WSM) by Fishburn in 1967
b) Weighted Product Model (WPM) by Bridgman 1922
c) ELimination and Choice Expressing Reality (ELECTRE) by Benayoun et al. 1966
d) Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS) by Hwang and Yoon 1981
e) Multi-Attribute Utility Theory (MAUT) by Edwards and Newman 1982
f) Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) by Brans and Vincke 1985
g) VIseKriterijumskaOptimizacija I KomprominsnoResenje (VIKOR) by Opricovic 1998
h) Analytic Hierarchy Process (AHP) by Saaty, 1970's

1. Weighted Sum Model (WSM):

a. <u>Steps:</u>

- Calculate: $J_{weightedsum} = w_1 J_1 + w_2 J_2 + \cdots w_m J_m$

Where w_i (i=1, 2…m) is a weighing factor for i^{th} objective function and J is a function of designed vector. The best alternative is chosen as max ($J_{weightedsum}$) [9].

b. Advantages:
- Simple computation.
- Suitable for single dimension problem [9].

c. Disadvantages:
- Sensitivity to units' ranges and exaggeration of specific scores [10].
- Only a basic estimate of one's penchant function.
- Fails to integrate multiple preferences [9].

d. Areas of Application:
Structural Optimization, and energy Planning [9]

2. Weighted Product Model (WSM):

a. Steps:
- Calculate: $P = \prod_{j=1}^{M}[(m_{ij})_{normal}]^{w}$
Where P is the overall score of the alternative, m_{ij} is the normalized value of an attribute, *w* is the weight and M is the number of criteria [9].

b. Advantages:
- Labelled to solve decision problems involving criteria of same type.
- Uses relative values and thus eliminates problem of homogeneity [9].

c. Disadvantages:
- Sensitivity to units' ranges and exaggeration of specific scores [10].
- Leads to undesirable results as it priorities or deprioritize the alternative which is far from average [9].

d. Areas of Application:
- Division of labor in a process based on various elements, and bidding strategies [9]

3. Elimination and Choice Expressing Reality (ELECTRE):

a. Steps:
Steps are based on three pillars:
- Determination of threshold function.
- Concordance index and Discordance index.
- Outranking degree [10].

b. Advantages:
- Takes uncertainty and vagueness into account [10].
- Deals with both quantitative and qualitative features of criteria [9].
- Final results are validated with reasons [9].
- Deals with heterogeneous scales [9].

c. Disadvantages:
- Process and outcome can be difficult to explain in layman's terms Outranking causes the strengths and weaknesses of the alternatives to not be directly identified [10].
- Less versatile.
- Demands good understanding of objective specially when dealing with quantitative features [9].

d. Areas of Application:
Energy management [9, 10], economics, environmental, water management [10], business management, information technology & communication, financial management [9] and transportation problems [9, 10].

4. Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS):

a. Steps:
- Calculation of matrices.
- Normalized and decision.
- Calculation of positive and negative ideal solutions.
- Calculation of separation and relative closeness. [9].

b. Advantages:
- Has a simple process [10].
- Easy to use and program [10].
- The number of steps remains the same regardless of the number of attributes [10].
- Works with fundamental ranking [9].
- Makes full use of allocated information [9].
- The information need not be independent [9].

c. Disadvantages:
- Its use of Euclidean Distance does not consider the correlation of attributes/ doesn't consider any difference between negative and positive values [9, 10].
- Difficult to weight and keep consistency of judgment [10].

d. Areas of Application:
Supply chain management and logistics [9, 10], chemical engineering [9, 10], manufacturing systems, business and marketing, environmental, human resources [10], energy management [9] and water resources management [9, 10].

4. Multi-Attribute Utility Theory (MAUT):

a. Steps:
- Identify dimensions of each objective and assign weight to each.
- Calculation of % weight and updating values based on weight assigned to options of each dimension.

- Multiplication of updated vales of weight and previously obtained values.
- Add product of each dimensions to get final sum for each options and thereby determine the decision. [9].

b. <u>Advantages:</u>
- Takes uncertainty into account [10].
- Can incorporate preferences [10].
- Accounts for any difference in any criteria [9].
- Simultaneously compute preference order for all alternatives [9].
- Dynamically updates value changes due to any impact [9].

c. <u>Disadvantages:</u>
- Needs a lot of input [10].
- Preferences need to be precise [10].
- Difficult to have precise input from decision maker [9].
- Outcome of the decision criteria is uncertain [9].

d. <u>Areas of Application:</u>
Finance, water management, energy management, agriculture [10], city planning, economic policy [9, 10], and government policy [9].

5. Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE):

a. <u>Steps:</u>
- Finding evaluation matrix and comparing them pairwise considering every single criteria.
- Assignment of preference function with values from 0 to 1 depending on the difference between pairs.
- Calculation of global matric and determining the rank by adding the column which express the supremacy of one alternative over the other [9].

b. <u>Advantages:</u>
- Easy to use [10].
- Does not require assumption that criteria are proportionate [10].
- Involves group level decision [9].
- Deals with qualitative and quantitative and qualitative information [9].
- Incorporate uncertain and fuzzy information [9].

c. <u>Disadvantages:</u>
- Does not provide a clear method by which to assign weights [10].
- Doesn’t structure the objective properly [9].
- Depends on the decision maker to assign weight [9].
- Complicated and so users are limited to experts [9].

d. Areas of Application:
Environmental, hydrology, water management, business and finance, chemistry, logistics and transportation, manufacturing and assembly, energy, agricultures [10], risk analysis, structural analysis, and mining Engineering [9]

6. VIseKriterijumskaOptimizacija I KomprominsnoResenje (VIKOR):

a. Steps:

- Determination of best and worst values.
- Calculation of values of Sj and Rj, where Sj is weighted and normalized Manhatten distance, Rj is weighted and normalized Chebyshev distance.
- Calculation of Qj, the computation index of VIKOR
- Ranking of alternatives and sorting by values of S, R and Q leading to formation of three list.
- A compromise solution from the final three rank lists [9].

b. Advantages:
- An updated version of TOPSIS [9].
- Calculates ration of positive and negative ideal solution thereby removing the impact [9].

c. Disadvantages:
- Difficulty when conflicting situation arises.
- Need modification while dealing with some terse data as it become difficult to model a real time model [9].

d. Areas of Application:
Mechanical engineering, manufacturing engineering, energy policy, business Management, medicine and health [9].

7. Analytic Hierarchy Process (AHP):

a. Steps:

- Defining objective into a hierarchical model.
- Determining weights for each criteria.
- Calculating score of each alternative considering criteria.
- Calculating overall score of each alternative [9].

b. Advantages:
- Easy to use/doesn’t involve complex mathematics [9, 10].
- Scalable [10].
- Hierarchy structure can easily adjust to fit many sized problems/adaptable [9, 10].
- Not data intensive [10].
- Intuitive and has the ability to handle criteria qualitative and quantitatively [10].

c. Disadvantages:
- Problems due to interdependence between criteria and alternatives can lead to inconsistencies between judgment and ranking criteria/hazardous results [9, 10].
- Involvement of more decision maker can make the problem more complicate while assigning weights (are judgmental and based on decision maker preference) [9, 11].
- Demands data collected based on Experience [9].
- Accuracy in this method can be widely varied in subjective problems [11].

d. Areas of Application:
Performance-type problems, political strategy [10], resource management, corporate policy and strategy, public policy and energy planning [9, 10], and logistics & transportation engineering [9].

E. Conclusion and Future Work

Considering the growing demand for energy worldwide and other factors, many countries have endorsed strategies for a transition to low carbon economies with a conspicuous attention on renewables worldwide. Careful selection of energy investment projects and efficient use of resources is gaining importance. We took the case of Lebanon regarding its fiscal deficit and economic situation to enhance an insight strategic energy planning for the site selection problem of renewable energy investments.

Moreover, to deploy a solar or wind project on a utility-scale, several criteria and factors should be considered with the aim of optimizing the location which will result in more efficient system, more economic to supply the needed customers and less impact on the environment. Site selection criteria were selected by the different scholars for the different renewable energy technologies. Likewise, the wind power site selection problem, in general, involves different stakeholders such as the regulatory authority, investors and society, where each party can pursue different types of priorities and preferences. Together with this, the different topographical or other sort of properties, rules and regulations, as well as commonly accepted criteria makes the site selection procedure multidimensional. In the light of this multi-dimensionality, we propose a decision-aiding approach on the site selection problem through an integration of Geographic Information Systems and Multiple Criteria Decision Analysis together. A literature review of the different multi-criteria decision making methods and a know-how of using the GIS software was done during this proposal phase.

The proposed methodology consists of pre-elimination of infeasible sites, ranking, and sorting of available site selection criteria. It involves both handling of deterministic and uncertain data. In such a manner, it provides a boutique approach to the initial problem and provides different types of results. Besides, it suggests a structural procedure and is applicable to other types of site selection problems with the related criteria depending on the problem.

The selection problem will be induced to specify land areas (fields) for implementing feasible renewable energy projects after an elimination of infeasible areas in the Geographic Information System and applying appropriate MCDM methods; the results are presented in terms of fields. Furthermore, the electric power generation potential for the selected alternatives will be calculated.

The proposed approach can address different stakeholders and has a flexible design that can reflect different preferences of the dealing parties and is applicable to any potential area. That’s why we are thinking of developing a platform that will help the government to organize and establish this studied energy planning to help students work on projects and develop their career.

CHAPTER III

PROPOSED METHODOLOGY

A. Study Area

Lebanon, a developing country, is located on the eastern edge of the Mediterranean Sea between the North Latitudes 33° 03’ 38” and 34° 41’ 35” and East Longitudes 35° 06’ 22” and 36° 37’ 22”. It covers an area of about 10,452 km2, and has a coastline of about 220 km long. Although its land area is very small, Lebanon has four different topographical areas: a narrow coast plain, two parallel mountainous regions: Mount Lebanon and Anti-Lebanon Range separated by an inland plateau, Bekaa valley. As a result of this diversity, the climate varies is Lebanon and from one place to another: mild to cool wet winters, and hot dry summers; with the temperature in the capital Beirut ranging from 5 °C in winter to 36 °C in summer. The Lebanese Mountains experience heavy winter snows. Moreover, Lebanon has a high population density with relatively high standards of living, which reflects a relatively large energy demand. The population is around 4 million and it has $4010 per capita Gross National Income (GNI) [16]. Lebanon meets nearly all its energy needs from the importation of oil products because it currently lacks the conventional fossil fuel energy resources and is not effectively benefiting from the available renewable energy resources. In 2008, more than 5 million toe (tons of oil equivalent) were imported, of which 49% were consumed for electricity generation. In the same year, renewable energy shared only 3.7% of the total primary energy supply (TPES) [16].

Renewable energy plays a marginal role in the energy balance of Lebanon. Hydropower was the unique renewable source used in electricity generation although Lebanon has the potential to benefit from other resources - especially solar and wind. Lebanon is rich in solar irradiation during almost 300 days a year, where this huge solar energy could be exploited to heat domestic water through the use of solar absorbing collectors or to generate electricity through photovoltaic modules (PV) or concentrating solar power systems (CSP). Concerning wind energy, the National Wind Atlas for Lebanon estimated a wind potential of at least 1500 MW [17]; however, most high wind speeds exist in remote areas, specifically on top of mountains, where the total wind power investment may be very expensive. Furthermore, the Municipal Solid Waste (MSW), an important biomass resource, exists in Lebanon. It could provide about 107 MW of the electricity needs based on availability rate of 4300t/day and an electrical generation rate of 600 kWh/t [18]. Moreover, accessible biogas and biodiesel are supposed to cover 4% of the Lebanese electrical needs [18]. Moving on to the geothermal energy, and considering the historical fact that some regions in Lebanon (extreme north and extreme southeast) used to be volcanic; hence, there is a high probability of finding important geothermal energy in the country. Although significant potentials of important renewable energy resources (solar, wind, hydro, geothermal, and biomass) exist in Lebanon, several barriers are preventing the development of their technologies.

Thus, in order to overcome these barriers, an energy plan is recommended to develop the renewable energy strategy and enhance investment in the RE sector.

B. Datasets and Site Selection Criteria Questionnaire

Upon previewing the Lebanese electrical energy situation, adopting renewable energy projects is critical to enhance economic growth. However, the renewable energy site selection is one of the most important, yet challenging task, when developing renewable energy plants. In other words, site selection plays an important role in the entire life cycle of the proposed renewable energy power plant project. Thus, the identification of preferable locations for renewable energy systems is problematic; hence, requiring a decision made after evaluating the potential of the resources together with economic and environmental limitations; taking into account many factors such as weather, geology, social acceptance, distance to infrastructure, etc.

So, a literature review was done, including a list of site selection criteria for the different renewable energy resources. To make this list context-sensitive for Lebanon, a questionnaire was conducted in favor of narrowing these selection criteria from experts' perspective. 9 responses from experts in Lebanon were collected and opinions were treated equally along the work analysis. The data sets for these criteria were collected from different resources and some were generated using GIS. Maps were updated and developed according to the constraints and restrictions explored from experts' opinion and the literature review.

Then, a multi-criteria decision making approach was proposed as a method to process available technical information to support decision in selecting the appropriate energy system. AHP was chosen to assign weights to the factor criteria. The importance of each factor criterion over the other was then determined and quantified. The suitability values and the weights obtained from the AHP methods were combined into a GIS to calculate suitability values of the land mapping units for each map type. The scores obtained from this calculation were classified from most suitable to least suitable. In the end, a new map of Lebanon will be generated, showing the optimal site location for the specific renewable energy resources.

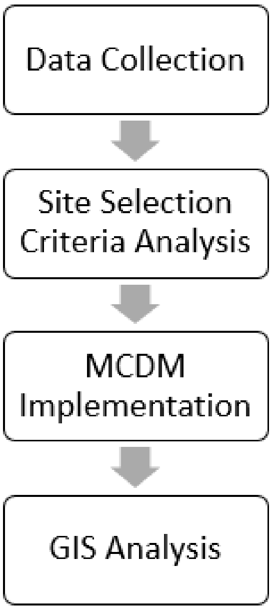


Figure 2. The Proposed methodology

Step 1: Data Collection
Data corresponding to site selection criteria were collected from different resources.

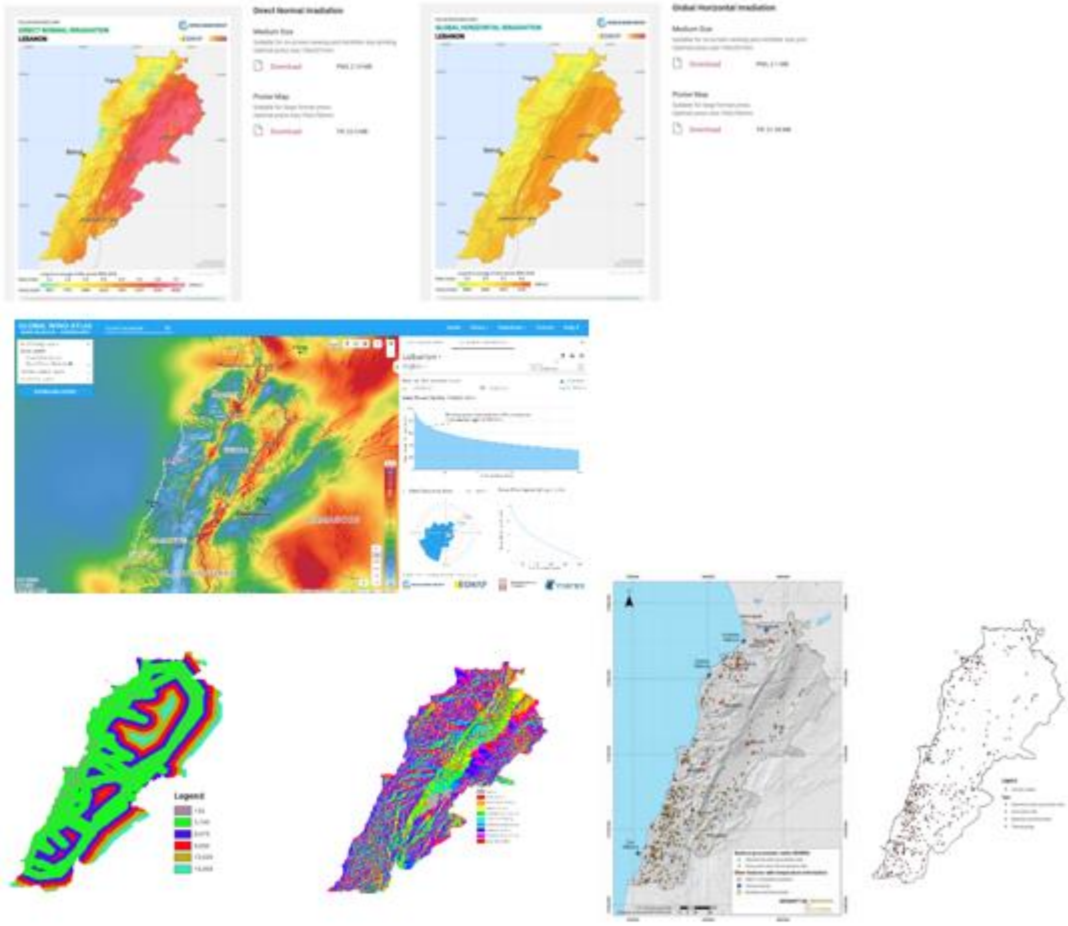


Figure 3. Data collected from different resources

There were several limitations at the data collection stage in Lebanon when it comes to biomass and geothermal technologies. These limitations include lack of data and lack of measurement equipment. Therefore, the analysis in these 2 specific areas was insufficient compared to the other areas studied. Site selection criteria for these 2 technologies were limited to the available data in Lebanon. Data was especially limited for biomass and geothermal energy.

Step 2: Site Selection Criteria Analysis

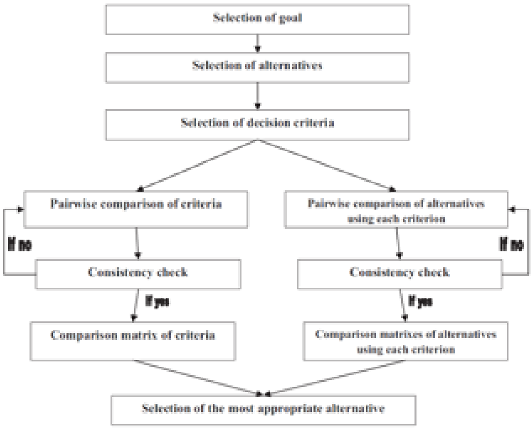
A questionnaire related to site selection criteria for renewable energy resources was conducted based on the literature review findings. This questionnaire aims at finding a selected range for Lebanon and ranking criteria according to the country specification. 9 persons from the energy field participated in this questionnaire, giving their expert opinion to select criteria and specify ranges specifically for Lebanon (see Appendix 1).

Figure 4. Site selection criteria questionnaire

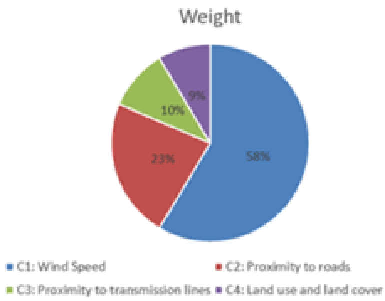
Some criteria were selected and others were eliminated.

Step 3: MCDM Implementation

Analytical Hierarchy Process was used to assign weights to each evaluation criteria, and thus determined their relative importance in the final decision. The method is based on pairwise comparison within a reciprocal matrix, in which the number of rows and columns is defined by the number of criteria. Note that the average opinion of each site selection criterion for each renewable energy technologies of the 9 expert from the questionnaire were used to construct the pairwise matrix. Afterward. this process is generating an auxiliary matrix – normalized pairwise comparison matrix in which the value in each cell is the result of the division of each value judgment by the sum of the corresponding column. Finally, the average of normalized values of rows is obtained, which corresponds to the priority vector. This is normalized by dividing each vector value by n (the number of vectors), thus obtaining the normalized overall priority vector, representing all factor weights. Implementation of this method is shown in the next chapter for each technology.



$$Aw = \begin{bmatrix} 1 & p & q \\ 1/p & 1 & r \\ 1/q & 1/r & 1 \end{bmatrix}$$



Score of criteria I to criteria j (Pij)	Definition
1	Criteria i and j are of equal importance
3	Criteria i is slightly more important than j
5	Criteria i is moderately more important than j
7	Criteria i is strongly more important than j
9	Criteria i is extremely more importance than j
2, 4, 6, 8	Intermediate values

Table 11. Preference score values interpretation

ID	Criteria name	Ranking of the experts
C1	Wind power density	1
C2	Slope	0.75
C3	Land use and land cover	0.857143

Table 18. Selected criteria among the experts' response

Criteria	C1	C2	C3
C1	1	7	5
C2	0.14	1	0.33
C3	0.2	3	1
Sum:	1.34	11	6.33

Table 19. The pairwise matrix [C]

Criteria	C1	C2	C3	Weight (%)	Weight [W]
C1	0.744	0.64	0.79	72.35	0.72
C2	0.106	0.091	0.05	8.33	0.08
C3	0.149	0.272	0.15	19.32	0.19

Table 20. The normalized matrix

Consistency check:

Determine the weight sums vector: [1]=[C][W]	Find the consistency vector: {Consis}=Dot Product[1].[1/W]
2.272592	3.141082
0.251061	3.013655
0.587811	3.042719

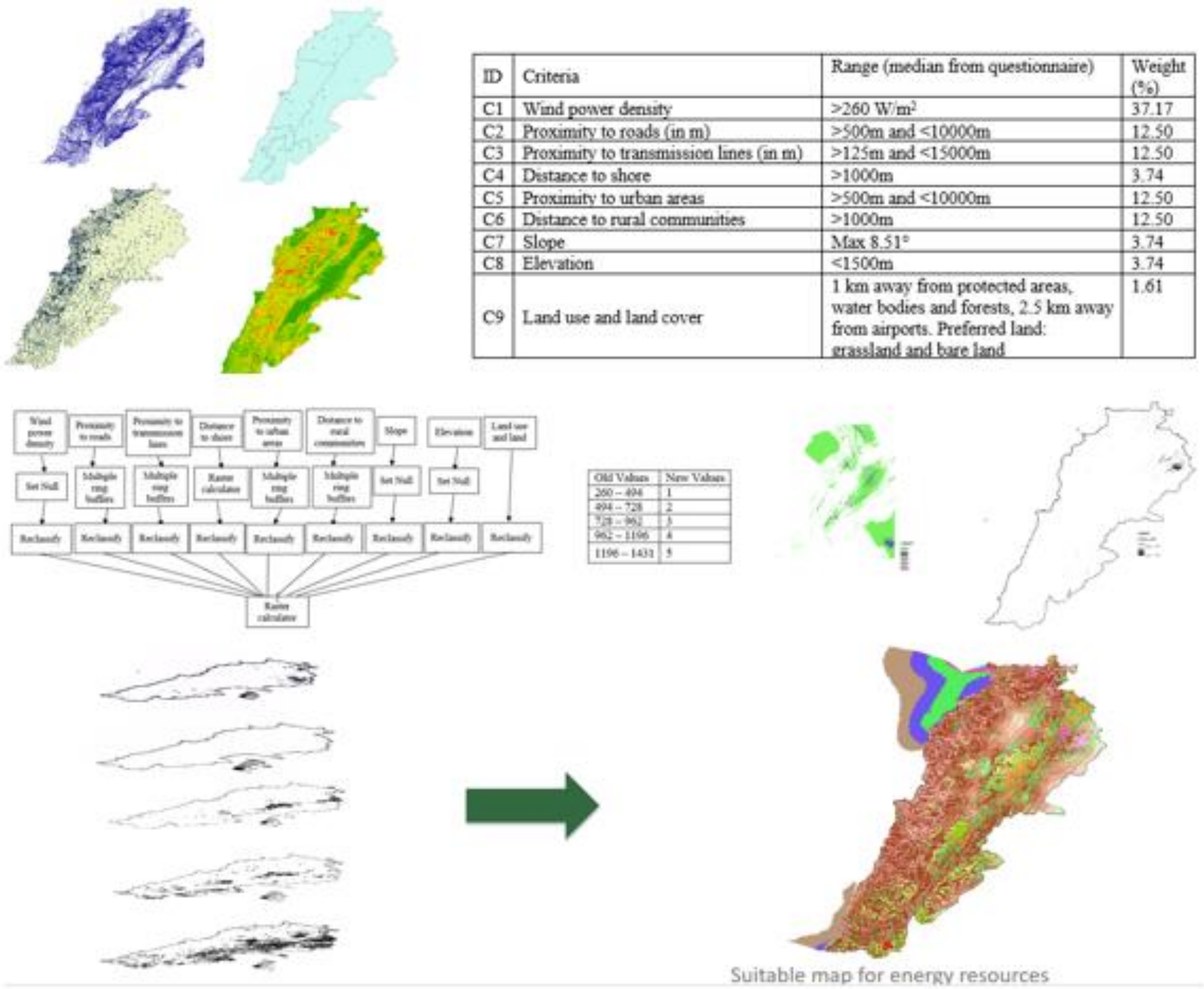
Table 21. Consistency check tables

Figure 5. AHP process for weighting criteria

Step 4: GIS Analysis

At this stage, GIS was used for editing data and analysis.

Criteria maps were created and ranges were applied for each criteria maps and corresponding renewable energy resources. Weighted obtained from the MCDM method were specified for each criteria. Finally, suitable site were obtained from the intersection of all these maps.



ID	Criteria	Range (median from questionnaire)	Weight (%)
C1	Wind power density	>260 W/m²	37.17
C2	Proximity to roads (in m)	>500m and <10000m	12.50
C3	Proximity to transmission lines (in m)	>125m and <15000m	12.50
C4	Distance to shore	>1000m	3.74
C5	Proximity to urban areas	>500m and <10000m	12.50
C6	Distance to rural communities	>1000m	12.50
C7	Slope	Max 8.51°	3.74
C8	Elevation	<1500m	3.74
C9	Land use and land cover	1 km away from protected areas, water bodies and forests, 2.5 km away from airports. Preferred land: grassland and bare land	1.61

Old Values	New Values
260 – 494	1
494 – 728	2
728 – 962	3
962 – 1196	4
1196 – 1431	5

Figure 6.GIS Analysis

CHAPTER IV

SITE SELECTION CRITERIA FOR RENEWABLE ENERGY TECHNOLOGIES

In this research, we tried to find out all the important factors that can reflect the merits of site selection through the literature review. Moreover, our study area is contextualized within Lebanon. Therefore, the relevant technical specifications and expert opinions should be taken into consideration. Based on this, some similar indicators are removed and other selected indicators are classified reasonably.

In this chapter, site selection criteria results from the literature review are presented. A questionnaire was administered aiming at finding a selected range for Lebanon and ranking criteria according to the country's specification. At the end of the chapter, analyzed site selection criteria were selected for each technology and appropriate ranges were set for the study case of Lebanon.

A. Site Selection Criteria Results from the Literature Review

From the conducted literature reviews, 23 criteria were collected for the different renewable energy technologies. Below is a list of the site selection criteria followed by the number of references for each technologies.

Table 2. Site selection criteria from the literature review

ID	Criterion	Technology					
		Onshore Wind	Offshore Wind	CSP	PV	Biomass	Geothermal
		Total number of articles: 24	Total number of articles: 23	Total number of articles: 13	Total number of articles: 39	Total number of articles: 13	Total number of articles: 3
		Frequency					
1	Wind speed	23	22	0	0	0	0
2	Wind power density	12	17	0	0	0	0
3	Wind direction and wind frequency	11	18	0	0	0	0
4	Turbulence intensity	7	15	0	0	0	0
5	Solar irradiance	0	0	8	26	0	0
6	Proximity to roads	22	9	5	21	11	2
7	Proximity to transmission lines	19	20	4	24	3	1
8	Distance to shore	1	11	0	3	0	0
9	Proximity to urban areas	20	4	2	21	0	0
10	Distance to rural communities	6	1	1	1	0	0

11	Population density	10	8	2	7	6	0
12	Slope	18	8	5	25	5	2
13	Elevation	13	8	1	6	1	0
14	Aspect	0	0	6	17	0	0
15	Land ownership	2	2	1	3	0	0
16	Foundation and soil quality	3	3	0	2	0	0
17	Land use and land cover	19	9	9	26	9	2
18	Noise	4	4	0	0	0	0
19	Bird strikes	4	4	0	0	0	0
20	Visual impacts	2	2	0	1	1	1
21	Water depth	0	11	0	0	0	0
22	Distance to waterways	5	7	0	0	0	0
23	Water availability	0	0	7	15	1	0

A framework of the indicator system is obtained from the literature review. However, this system must be refined according to some circumstances in the study area. Accordingly, a questionnaire was administered aiming at depicting the ranking criteria according to the country's specification. Different experts in renewable energy systems filled the questionnaire and 9 responses were collected.

B. Site Selection Criteria Results from the Questionnaire

Experts in renewable energy field from Lebanon have participated in the study and have provided their insight to help us rank the site selection criteria. Below is a table of the obtained results.

Table 3. Site selection criteria from the questionnaire

ID	Criterion	Technology					
		Onshore Wind	Offshore Wind	CSP	PV	Biomass	Geothermal
		Number of responses if applicable Total number of responses: 9 (yes, no, no answer)					
1	Wind speed	9	9	2	6	1	1
2	Wind power density	7	7	0	0	0	0
3	Wind direction and wind frequency	6	6	1	2	1	1
4	Turbulence intensity	6	6	0	0	0	0
5	Solar irradiance	0	0	8	8	0	0
6	Proximity to	9	4	9	9	6	6

	roads						
7	Proximity to transmission lines	9	3	9	9	4	4
8	Distance to shore	8	2	7	7	1	1
9	Proximity to urban areas	9	3	7	8	2	2
10	Distance to rural communities	9	2	6	5	4	3
11	Population density	2	2	1	2	4	4
12	Slope	8	6	6	8	4	4
13	Elevation	8	3	8	7	4	4
14	Aspect	2	1	2	6	2	2
15	Land ownership	6	5	6	6	6	4
16	Foundation and soil quality	8	4	6	5	2	2
17	Land use and land cover	7	6	6	6	6	6
18	Noise	8	2	1	1	2	2
19	Bird strikes	8	8	2	1	1	1
20	Visual impacts	5	2	6	4	3	3
21	Water depth	3	5	1	2	1	1
22	Distance to waterways	5	3	2	2	3	3
23	Water availability	1	1	4	4	3	3

We aim at selecting relevant and appropriate criteria for site selection of renewable energy systems in Lebanon. From the literature review, a qualitative picture of site selection criteria was illustrated. Then, experts’ opinion refined these criteria, and a quantitative picture of site selection criteria for Lebanon was built.

The decision of selection criteria was formed from the experts’ responses on the questionnaire 50% (the majority) were selected as suitable criteria for each renewable energy technology.

It is notable to mention that some criteria were merged.

Below is the decision of each technology:

C. Site Selection Criteria Decision for Renewable Energy Systems

1. Technology 1: Onshore Wind Energy

Table 4. Site selection criteria for technology 1

ID	Criterion	Rank from the questionnaire (Number of applicable responses/Total number of responses)	Decision: criteria selected (above 0.5)	Final decision
1	Wind speed	1	Yes	No[1]
2	Wind power density	0.777777778	Yes	Yes
3	Wind direction and wind frequency	0.75	Yes	No[2]
4	Turbulence intensity	0.75	Yes	No[3]
5	Solar irradiance	0	No	No
6	Proximity to roads	1	Yes	Yes
7	Proximity to transmission lines	1	Yes	Yes
8	Distance to shore	1	Yes	Yes
9	Proximity to urban areas	1	Yes	Yes
10	Distance to rural communities	1	Yes	Yes
11	Population density	0.285714286	No	No
12	Slope	1	Yes	Yes
13	Elevation	1	Yes	Yes
14	Aspect	0.333333333	No	No
15	Land ownership	0.857142857	Yes	No[4]
16	Foundation and	0.75	Yes	No[5]

---

[1] The wind power density is expressed as:

$$P = \frac{1}{2}\rho_{air} * Area * V^3$$

The wind speed V is the most important factor and the air density ρ_{air} can affect the capacity factor of a wind turbine performance by 1-4% as a reduction range.
So, criterion 1 (wind speed) was merged with criterion 2 (wind power density). In this case, the maximum rank from this criteria is 2 that is the wind speed.

[2] Data are not available. Moreover, wind turbines can adapt to the variation of wind direction.

[3] Data are not available. Moreover, wind turbines can adapt to the variation of turbulence intensity.

[4] This criterion is common to all renewable energy technologies and can be eliminated.

[5] The soils of Lebanon are typically Mediterranean, generally calcareous, except for the sandy soils formed on the basal cretaceous strata of the Akkar Plain and the alluvial soils of central and western Bekaa Valley [20]. This will not affect the assigned technology.

	soil quality			
17	Land use and land cover	1	Yes	Yes
18	Noise	1	Yes	No[6]
19	Bird strikes	1	Yes	No[7]
20	Visual impacts	0.714285714	Yes	No[8]
21	Water depth	0.428571429	No	No
22	Distance to waterways	0.714285714	Yes	No[9]
23	Water availability	0.166666667	No	No

Result adjustment:

The wind power density criterion is considered the most important of all criteria. Although the results of the questionnaire do not reveal this fact, where the wind power density criterion is as equal as the criteria of proximity to road, proximity to transmission lines, distance to shore, distance to rural communities, slope, elevation and land use and land cover. However, one cannot build a wind farm in a place that is close to transmission lines but has low wind speed. That's why we have to differentiate the wind power density criterion by lifting up its rank.
Furthermore, the "No answer" is taken into consideration to differentiate between criteria because of the narrow scoring.
We re-scored the criteria according to the following classification:
We have 4 categories:
- Category 1: which includes criterion 1 as the most important criterion; it will take the value of 1.
- Category 2: which includes criteria 2, 3, 5 and 6. Those that had the same score as criterion 1 but are less important; they will take 0.75 as a score (1-1/4=0.75; score 1 was fragmented into 4*0.25. 4 for 4 categories)
- Category 3: which includes criteria 4, 7 and 8. In those criteria, we have a "No answer" result. Their score is as follows: 1-2*0.25=0.5
- Category 4: which includes criterion 9. In this criterion, we have 2 "No answer" result, and the score is as follows: 1-3*0.25=0.25
We will obtain the following ranking:

[6] This criterion can be merged with distance to rural communities and proximity to urban areas criteria.
[7] This criterion can be merged with land use and land cover criterion, considering bird strikes as protected areas.
[8] This criterion can be merged with distance to rural communities and proximity to urban areas criteria.
[9] This criterion can be merged with land use and land cover criterion.

Table 5. Ranking adjustment

ID	Criterion	Rank from the questionnaire (Number of applicable responses/Total number of responses)
1	Wind speed	1
2	Proximity to roads	0.75
3	Proximity to transmission lines	0.75
4	Distance to shore	0.5
5	Proximity to urban areas	0.75
6	Distance to rural communities	0.75
7	Slope	0.5
8	Elevation	0.5
9	Land use and land cover	0.25

2. Technology 2: Offshore Wind Energy

Table 6. Site selection criteria for technology 2

ID	Criterion	Rank from the questionnaire (Number of applicable responses/Total number of responses)	Decision: criteria selected (above 0.5)	Final decision
1	Wind speed	1	Yes	No[10]
2	Wind power density	0.777777778	Yes	Yes
3	Wind direction and wind frequency	0.75	Yes	No[11]
4	Turbulence intensity	0.75	Yes	No[12]
5	Solar irradiance	0	No	No
6	Proximity to roads	0.5	No	No
7	Proximity to transmission lines	0.375	No	No
8	Distance to shore	0.25	No	No
9	Proximity to urban areas	0.5	No	No
10	Distance to rural communities	0.333333333	No	No
11	Population density	0.285714286	No	No

[10] Refer to footnote 1.
[11] Refer to footnote 2.
[12] Refer to footnote 3.

12	Slope	0.75	Yes	Yes
13	Elevation	0.375	No	No
14	Aspect	0.166666667	No	No
15	Land ownership	0.714285714	Yes	No[13]
16	Foundation and soil quality	0.5	No	No
17	Land use and land cover	0.857142857	Yes	Yes
18	Noise	0.285714286	No	No
19	Bird strikes	1	Yes	No[14]
20	Visual impacts	0.25	No	No
21	Water depth	0.714285714	Yes	No[15]
22	Distance to waterways	0.428571429	No	No
23	Water availability	0.166666667	No	No

3. Technology 3: Concentrated Solar Power Energy

Table 7. Site selection criteria for technology 3

ID	Criterion	Rank from the questionnaire (Number of applicable responses/Total number of responses)	Decision: criteria selected (above 0.5)	Final decision
1	Wind speed	0.25	No	No
2	Wind power density	0	No	No
3	Wind direction and wind frequency	0.142857143	No	No
4	Turbulence intensity	0	No	No
5	Solar irradiance	1	Yes	Yes
6	Proximity to roads	1	Yes	Yes
7	Proximity to transmission lines	1	Yes	Yes
8	Distance to shore	0.875	Yes	Yes
9	Proximity to urban areas	0.875	Yes	Yes
10	Distance to rural communities	0.857142857	Yes	Yes
11	Population density	0.142857143	No	No

[13] Refer to footnote 4.
[14] Refer to footnote 7.
[15] In spite of the geology of Lebanon, water depth range falls in a safe range.

12	Slope	0.857142857	Yes	Yes
13	Elevation	1	Yes	Yes
14	Aspect	0.333333333	No	No
15	Land ownership	0.857142857	Yes	No[16]
16	Foundation and soil quality	0.75	Yes	No[17]
17	Land use and land cover	0.857142857	Yes	Yes
18	Noise	0.125	No	No
19	Bird strikes	0.25	No	No
20	Visual impacts	0.75	Yes	No[18]
21	Water depth	0.142857143	No	No
22	Distance to waterways	0.285714286	No	No
23	Water availability	0.66666667	Yes	Yes

4. Technology 4: Photovoltaic Energy

Table 8. Site selection criteria for technology 4

ID	Criterion	Rank from the questionnaire (Number of applicable responses/Total number of responses)	Decision: criteria selected (above 0.5)	Final decision
1	Wind speed	0.66666667	Yes	No[19]
2	Wind power density	0	No	No
3	Wind direction and wind frequency	0.285714286	No	No
4	Turbulence intensity	0	No	No
5	Solar irradiance	1	Yes	Yes
6	Proximity to roads	1	Yes	Yes
7	Proximity to transmission lines	1	Yes	Yes
8	Distance to shore	0.875	Yes	Yes
9	Proximity to urban areas	0.888888889	Yes	Yes
10	Distance to rural communities	0.714285714	Yes	Yes
11	Population density	0.285714286	No	No
12	Slope	1	Yes	Yes
13	Elevation	1	Yes	Yes

[16] Refer to footnote 4.
[17] Refer to footnote 5.
[18] Refer to footnote 6.
[19] View the history of wind data in Lebanon; this criteria can’t affect the system badly.

14	Aspect	1	Yes	Yes
15	Land ownership	0.857142857	Yes	No[20]
16	Foundation and soil quality	0.625	Yes	No[21]
17	Land use and land cover	0.857142857	Yes	Yes
18	Noise	0.125	No	No
19	Bird strikes	0.125	No	No
20	Visual impacts	0.5	No	No
21	Water depth	0.285714286	No	No
22	Distance to waterways	0.333333333	No	No
23	Water availability	0.66666667	Yes	No[22]

5. Technology 5: Biomass Energy

Table 9. Site selection criteria for technology 5

ID	Criterion	Rank from the questionnaire (Number of applicable responses/Total number of responses)	Decision: criteria selected (above 0.5)	Final decision
1	Wind speed	0.125	No	No
2	Wind power density	0	No	No
3	Wind direction and wind frequency	0.166666667	No	No
4	Turbulence intensity	0	No	No
5	Solar irradiance	0	No	No
6	Proximity to roads	0.857142857	Yes	Yes
7	Proximity to transmission lines	0.571428571	Yes	Yes
8	Distance to shore	0.2	No	No
9	Proximity to urban areas	0.333333333	No	No
10	Distance to rural communities	0.8	Yes	No[23]
11	Population density	0.66666667	Yes	Yes

[20] Refer to footnote 4.
[21] Refer to footnote 5.
[22] Some feasible techniques cannot be used to clean the panels.
[23] Installing a biomass plant will create job opportunities for citizens. This feature is related to population density criterion more than distance to rural communities. That's why we can merge these 2 criteria and select the biggest rank for both.

12	Slope	0.571428571	Yes	Yes
13	Elevation	0.8	Yes	Yes
14	Aspect	0.4	No	No
15	Land ownership	0.8	Yes	No[24]
16	Foundation and soil quality	0.4	No	No
17	Land use and land cover	0.857142857	Yes	Yes
18	Noise	0.285714286	No	No
19	Bird strikes	0.142857143	No	No
20	Visual impacts	0.428571429	No	No
21	Water depth	0.166666667	No	No
22	Distance to waterways	0.6	Yes	No[25]
23	Water availability	0.6	Yes	Yes

6. Technology 6: Geothermal Energy

Table 10. Site selection criteria for technology 5

ID	Criterion	Rank from the questionnaire (Number of applicable responses/Total number of responses)	Decision: criteria selected (above 0.5)	Final decision
1	Wind speed	0	No	No
2	Wind power density	0	No	No
3	Wind direction and wind frequency	0	No	No
4	Turbulence intensity	0	No	No
5	Solar irradiance	0	Yes	Yes
6	Proximity to roads	0.857142857	Yes	Yes
7	Proximity to transmission lines	0.5	Yes	Yes
8	Distance to shore	0.166666667	No	No
9	Proximity to urban areas	0.5	No	No
10	Distance to rural communities	0.6	Yes	Yes
11	Population density	0.166666667	No	No
12	Slope	0.5	No	No
13	Elevation	0.5	No	No
14	Aspect	0.25	No	No
15	Land ownership	0.8	Yes	No[26]

[24] Refer to footnote 4.
[25] This criterion can be merged with land use and land cover criterion, proximity to rivers.
[26] Refer to footnote 4.

16	Foundation and soil quality	0.8	Yes	No[27]
17	Land use and land cover	1	Yes	Yes
18	Noise	0.142857143	No	No
19	Bird strikes	0.142857143	No	No
20	Visual impacts	0	No	No
21	Water depth	0.333333333	No	No
22	Distance to waterways	0.4	No	No
23	Water availability	0.66666667	Yes	No[28]

Results and Conclusion

The site selection of renewable energy systems is a complex decision-making problem that needs to consider many factors such as the wind and solar energy resources, the grid construction cost, the distance to load center, the economic and social factors, all of which can affect the economy of projects and may threat the safe and stable operation of the grid.

Therefore, we tried to find out all of the important factors that can reflect the merits of site selection through literature statistics and then obtain a more complete indicator system. However, redundant indicators are easily introduced. Therefore, the relevant technical specifications and expert opinions should be taken into consideration. Based on a conducted questionnaire, some similar indicators were reduced and merged, and all the selected indicators are classified reasonably for each renewable energy technology.

Note that criteria for biomass and geothermal energy are very limited and are only used here for illustrative purpose.

[27] Refer to footnote 5.

[28] Geothermal power production utilizes water in two major ways:

- The first method, which is inevitable in geothermal production, uses hot water from an underground reservoir to power the facility.
- The second is using water for cooling (for some plants only).

Note that geothermal fluid is considered a water resource, and therefore, the water availability criteria can be merge with the land use and land cover criteria.

CHAPTER V

IMPLEMENTATING MCDM FOR OPTIMAL RENEWABLE ENERGY SITE SELECTION IN LEBANON

Decision-making is about identifying and choosing alternatives to find the best solution that takes into account different factors while considering the decision-makers' expectations. Every single decision is made with regard to a certain environment. This environment is the collection of a set of information, alternatives, values and preferences available at the time when the decision must be made.

After selecting site criteria for each renewable energy technology, this chapter will contribute to finding the best decision of installing the specific technology, in a particular site, by implementing a multi-criteria decision making method.

One of the most popular multi-criteria decision-making methods (MCDM) is the Analytical Hierarchy Process (AHP). This is a theory of measurement for dealing with quantifiable and/or intangible criteria that has found rich applications in decision theory, conflict resolution and models of the brain. It is based on the principle that in order to make decisions, the experience and knowledge of people is as valuable as the data used. In this chapter, site selection criteria for each renewable energy technology will be weighted using the AHP methods. All the procedure will be shown in the next section.

A. The AHP Procedure, an Overview

The AHP is a decision support tool that can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub criteria, and alternatives. The pertinent data are derived by using a set of pairwise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria and the relative performance measures of the alternatives in terms of each individual decision criterion. If the comparisons are not perfectly consistent, it provides a mechanism for improving the consistency.

Applying the AHP model consists of several steps as shown below:

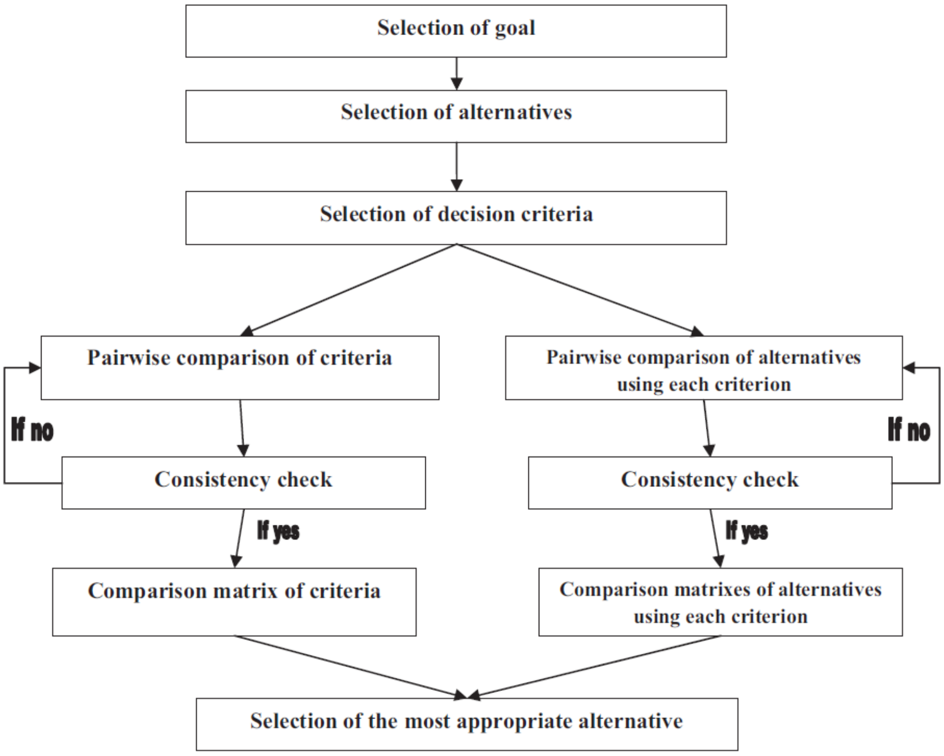


Figure 7. Steps of applying the Analytical Hierarchy Process model [19]

It starts with setting the goal followed by the selection of alternatives. Practical judgment is necessary for criteria selection. Pairwise comparisons are required among criteria.

Matrixes of pairwise comparisons are created by the experts on condition that judgments are evaluated to find suitable alternatives to estimate the associated absolute numbers from 1 to 9, the fundamental scales of the AHP. These comparisons are made using Saaty's discrete 9 value scale:

Table 11. Preference score values interpretation

Score of criterion I to criterion j (Pij)	Definition
1	Criteria i and j are of equal importance
3	Criteria i is slightly more important than j
5	Criteria i is moderately more important than j
7	Criteria i is strongly more important than j
9	Criteria i is extremely more important than j
2, 4, 6, 8	Intermediate values

$$Aw = \begin{bmatrix} 1 & p & q \\ 1/p & 1 & r \\ 1/q & 1/r & 1 \end{bmatrix}$$

The relative weights of A1, A2 and A3 can be determined from matrix A by normalizing it into a new matrix This process involves dividing the elements of each column by the sum of the elements of the same column. The desired relative weights of these alternatives are then computed as the row average of the new matrix.

Consistency check:
If the columns of A are identical, then the decision-maker exhibits perfect consistency in specifying the entries of the comparison matrix A. Mathematically, the matrix A is consistent if: a_{ij} x a_{jk}=a_{ik} for all values of i; j and k:
It is abnormal for all comparisons to be consistent. A reasonable level of inconsistency is expected and tolerated due to the nature of human judgment. To determine whether the level of inconsistency is 'reasonable', Saaty developed the following methodology:
Estimate the Consistency Index (CI) using:

$$CI = \frac{\lambda - n}{n - 1}$$

In this formula, n is the size of the matrix (n x n) and λ can be defined as the product of the weighted matrix Aw and the normalized matrix.
The Consistency Ratio (CR) can be estimated using:

$$CR = \frac{CI}{RC}$$

As a rule of thumb, if the CR value is equal to or less than 0.10, the pairwise comparison results are acceptable; otherwise, they should be rejected and revised.
The Random Consistency (RC) of the matrix A can be estimated using the following standard table:

Table 12. Random index for different values of number of elements

N	2	3	4	5	6	7	8	9	10	11	12
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53

B. The Implementation of the AHP Method

1. Case 1: Onshore Wind Energy

Table 13. Selected criteria among the experts' response

ID	Criterion name	Ranking of the experts
C1	Wind power density	1
C2	Proximity to roads (in m)	0.75
C3	Proximity to transmission lines (in m)	0.75
C4	Distance to shore	0.5
C5	Proximity to urban areas	0.75
C6	Distance to rural communities	0.75
C7	Slope	0.5
C8	Elevation	0.5
C9	Land use and land cover	0.25

Table 14. The pairwise matrix [C]

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1	5	5	7	5	5	7	7	9
C2	0.2	1	1	5	1	1	5	5	7
C3	0.2	1	1	5	1	1	5	5	7
C4	0.14	0.2	0.2	1	0.2	0.2	1	1	5
C5	0.2	1	1	5	1	1	5	5	7
C6	0.2	1	1	5	1	1	5	5	7
C7	0.14	0.2	0.2	1	0.2	0.2	1	1	5
C8	0.14	0.2	0.2	1	0.2	0.2	1	1	5
C9	0.11	0.14	0.14	0.2	0.14	0.14	0.2	0.2	1
Sum:	2.33	9.74	9.74	30.20	9.74	9.74	30.30	30.30	53

Table 15. The normalized matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	Weight (%)	Weight [W]
C1	0.43	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.17	37.17	0.37
C2	0.086	0.088	0.09	0.088	0.088	0.088	0.088	0.088	0.1	12.50	0.125
C3	0.086	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.1	12.50	0.125
C4	0.086	0.088	0.088	0.09	0.09	0.09	0.09	0.09	0.1	3.74	0.04
C5	0.086	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.1	12.50	0.125
C6	0.086	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.1	12.50	0.125
C7	0.086	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.1	3.74	0.04
C8	0.086	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.1	3.74	0.04
C9	0.052	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.033	1.61	0.02

Consistency check:

Table 16. Consistency check tables

Determine the weight sums vector: [1]=[C][W]	Find the consistency vector: {Consis}=Dot Product[1].[1/W]
3.802	10.228
1.248	9.988
1.248	9.988
0.345	9.240
1.248	9.988
1.248	9.988
0.345	9.240
0.345	9.240
0.151	9.40

Calculate the average element, λ= 9.700222
Calculate the consistency Index (CI):

$$CI = \frac{\lambda - n}{n - 1} = 0.0875$$

Calculate the Consistency Ratio (CR):

$$CR = \frac{CI}{RC} = 0.0604$$

CR<0.1, so it is consistent.
The following table sums up the selected criteria for onshore wind technology and their weight:

Table 17. Selected criteria for onshore wind energy and their weight

ID	Criterion	Weight (%)
C1	Wind power density	37.17
C2	Proximity to roads (in m)	12.50
C3	Proximity to transmission lines (in m)	12.50
C4	Distance to shore	3.74
C5	Proximity to urban areas	12.50
C6	Distance to rural communities	12.50
C7	Slope	3.74
C8	Elevation	3.74
C9	Land use and land cover	1.61

2. Case 2: Offshore Wind Energy

Table 18. Selected criteria among the experts' response

ID	Criterion name	Ranking of the experts
C1	Wind power density	1
C2	Slope	0.75
C3	Land use and land cover	0.857143

Table 19. The pairwise matrix [C]

Criteria	C1	C2	C3
C1	1	7	5
C2	0.14	1	0.33
C3	0.2	3	1
Sum:	1.34	11	6.33

Table 20. The normalized matrix

Criteria	C1	C2	C3	Weight (%)	Weight [W]
C1	0.744	0.64	0.79	72.35	0.72
C2	0.106	0.091	0.05	8.33	0.08
C3	0.149	0.272	0.15	19.32	0.19

Consistency check:

Table 21. Consistency check tables

Determine the weight sums vector: [1]=[C][W]	Find the consistency vector: {Consis}=Dot Product[1].[1/W]
2.272592	3.141082
0.251061	3.013655
0.587811	3.042719

Calculate the average element, λ= 3.065819

Calculate the consistency Index (CI):

$$CI = \frac{\lambda - n}{n - 1} = 0.032909$$

Calculate the Consistency Ratio (CR):

$$CR = \frac{CI}{RC} = 0.05674$$

CR<0.10, so the degree of consistency is considered satisfactory.
The following table sums up the selected criteria for offshore wind technology and their weight:

Table 22. Selected criteria for offshore wind energy and their weight

ID	Criterion	Weight (%)
C1	Wind power density	72..35
C2	Slope	8.33
C3	Land use and land cover	19.32

3. Case 2: CSP Energy

Table 23. Selected criteria among the experts' response

ID	Criterion name	Ranking of the experts
C1	Solar irradiation	1
C2	Proximity to roads (in m)	1
C3	Proximity to transmission lines (in m)	1
C4	Distance to shore	0.875
C5	Proximity to urban areas	0.875
C6	Distance to rural communities	0.857143
C7	Slope	0.857143
C8	Elevation	1
C9	Land use and land cover	0.857143
C10	Water availability	0.66666667

Table 24. The pairwise matrix [C]

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	1	1	5	5	5	5	1	5	9
C2	1	1	1	5	5	5	5	1	5	9
C3	1	1	1	5	5	5	5	1	5	9
C4	0.2	0.2	0.2	1	1	3	3	0.2	3	7
C5	0.2	0.2	0.2	1	1	3	3	0.2	3	7
C6	0.2	0.2	0.2	0.33	0.33	1	1	0.2	1	7
C7	0.2	0.2	0.33	0.33	0.33	1	1	0.2	1	7
C8	1	1	5	5	5	5	5	1	5	9
C9	0.2	0.2	0.33	0.33	0.33	1	1	0.2	1	7
C10	0.11	0.11	0.11	0.14	0.14	0.14	0.14	0.11	0.14	1
Sum:	5.11	5.11	5.11	23.13	23.13	29.14	29.14	5.11	29.14	72.00

Table 25. The normalized matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Weight (%)	Weight [W]
C1	0.19	0.20	0.20	0.22	0.22	0.17	0.17	0.20	0.17	0.13	18.54	0.19
C2	0.19	0.19	0.20	0.21	0.21	0.17	0.17	0.19	0.17	0.125	18.54	0.19
C3	0.19	0.19	0.19	0.21	0.21	0.17	0.17	0.19	0.17	0.125	18.54	0.19
C4	0.04	0.04	0.04	0.04	0.04	0.10	0.10	0.04	0.10	0.10	6.49	0.06

C5	0.04	0.04	0.04	0.04	0.04	0.10	0.10	0.04	0.10	0.097	6.49	0.06
C6	0.04	0.04	0.04	0.01	0.01	0.03	0.03	0.04	0.03	0.097	3.85	0.04
C7	0.04	0.04	0.04	0.01	0.01	0.03	0.03	0.04	0.03	0.097	3.85	0.04
C8	0.19	0.19	0.19	0.21	0.21	0.17	0.17	0.19	0.17	0.125	18.54	0.19
C9	0.04	0.04	0.04	0.01	0.01	0.03	0.03	0.04	0.03	0.097	3.85	0.04
C10	0.02	0.02	0.02	0.006	0.006	0.0049	0.0049	0.02	0.0049	0.014	1.28	0.01

Consistency check:

Table 26. Consistency check tables

Determine the weight sums vector: [1]=[C][W]	Find the consistency vector: {Consis}=Dot Product[1].[1/W]
2.084097	5.392541
2.084097	5.392541
2.084097	5.392541
0.714621	15.40862
0.714621	15.40862
0.396794	25.94089
0.396794	25.94089
2.084097	5.392541
0.396794	25.94089
0.130272	78.18793

Calculate the average element, λ= 10.80422
Calculate the consistency Index (CI):

$$CI = \frac{\lambda - n}{n - 1} = 0.089358$$

Calculate the Consistency Ratio (CR):

$$CR = \frac{CI}{RC} = 0.059972$$

CR<0.10, so the degree of consistency is considered satisfactory.
The following table sums up the selected criteria for CSP technology and their weight:

Table 27. Selected criteria for CSP energy and their weight

ID	Criterion	Weight (%)
C1	Solar irradiance	18.54
C2	Proximity to roads (in m)	18.54
C3	Proximity to transmission lines (in m)	18.54
C4	Distance to shore	6.49
C5	Proximity to urban areas	6.49
C6	Distance to rural communities	3.85
C7	Slope	3.85
C8	Elevation	18.54
C9	Land use and land cover	3.85
C10	Water availability	1.28

4. Case 4: PV Energy

Table 28. Selected criteria among the experts' response

ID	Criterion name	Ranking of the experts
C1	Solar irradiance	1
C2	Proximity to roads (in m)	1
C3	Proximity to transmission lines (in m)	1
C4	Distance to shore	0.875
C5	Proximity to urban areas	0.888889
C6	Distance to rural communities	0.714286
C7	Slope	1
C8	Elevation	1
C9	Aspect	1
C10	Land use and land cover	0.857143

Table 29. The pairwise matrix [C]

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	1	1	5	5	7	1	1	1	5
C2	1	1	1	5	5	7	1	1	1	5
C3	1	1	1	5	5	7	1	1	1	5
C4	0.2	0.2	0.2	1	0.33	5	0.2	0.2	0.2	3
C5	0.2	0.2	0.2	3	1	5	0.2	0.2	0.2	3
C6	0.14	0.1	0.14	0.2	0.2	1	0.14	0.14	0.14	0.2
C7	1	1	1	5	5	7	1	1	1	5
C8	1	1	1	5	5	7	1	1	1	5
C9	1	1	1	5	5	7	1	1	1	5
C10	0.2	0.2	0.2	0.33	0.33	5	0.2	0.2	0.2	1
Sum:	6.74	6.74	6.74	34.53	31.86	58	6.74	6.74	6.74	37.2

Table 30. The normalized matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Weight (%)	Weight [W]
C1	0.148	0.15	0.15	0.14	0.16	0.12	0.15	0.15	0.15	0.13	14.47	0.14
C2	0.148	0.148	0.15	0.144	0.157	0.12	0.148	0.148	0.148	0.13	14.47	0.14
C3	0.148	0.148	0.148	0.144	0.157	0.12	0.148	0.148	0.148	0.13	14.47	0.14
C4	0.029	0.029	0.029	0.029	0.01	0.09	0.03	0.03	0.03	0.08	3.84	0.04
C5	0.029	0.029	0.029	0.087	0.031	0.08	0.029	0.029	0.029	0.08	4.63	0.05
C6	0.021	0.021	0.021	0.005	0.006	0.017	0.021	0.021	0.021	0.005	1.62	0.02
C7	0.148	0.148	0.148	0.144	0.157	0.12	0.148	0.148	0.148	0.13	14.47	0.14
C8	0.148	0.148	0.148	0.144	0.157	0.12	0.148	0.148	0.148	0.13	14.47	0.14
C9	0.148	0.148	0.148	0.144	0.157	0.12	0.148	0.148	0.148	0.13	14.47	0.14
C10	0.029	0.029	0.029	0.0097	0.01	0.09	0.029	0.029	0.029	0.02	3.11	0.03

Consistency check:

Table 31. Consistency check tables

Determine the weight sums vector: [1]=[C][W]	Find the consistency vector: {Consis}=Dot Product[1].[1/W]
1.560472	10.78702
1.560472	10.78702
1.560472	10.78702
0.401706	10.45467
0.509425	11.00099
0.163346	10.09529
1.560472	10.78702
1.560472	10.78702
1.560472	10.78702
0.313857	10.08643

Calculate the average element, λ= 10.63595
Calculate the consistency Index (CI):

$$CI = \frac{\lambda - n}{n - 1} = 0.000578$$

Calculate the Consistency Ratio (CR):

$$CR = \frac{CI}{RC} = 0.000388$$

CR<0.10, so the degree of consistency is considered satisfactory.
The following table sums up the selected criteria for PV technology and their weight:

Table 32. Selected criteria for PV energy and their weight

ID	Criterion	Weight (%)
C1	Solar irradiance	14.47
C2	Proximity to roads (in m)	14.47
C3	Proximity to transmission lines (in m)	14.47
C4	Distance to shore	3.84
C5	Proximity to urban areas	4.63
C6	Distance to rural communities	1.62
C7	Slope	14.47
C8	Elevation	14.47
C9	Aspect	14.47
C10	Land use and land cover	3.11

5. Case 5: Biomass Energy

Table 33. Selected criteria among the experts' response

ID	Criterion name	Ranking of the experts
C1	Proximity to roads (in m)	0.857143
C2	Proximity to transmission lines (in m)	0.571429
C3	Population density	0.8
C4	Slope	0.571429
C5	Elevation	0.8
C6	Land use and land cover	0.857143
C7	Water availability	0.6

Table 34. The pairwise matrix [C]

Criteria	C1	C2	C3	C4	C5	C6	C7
C1	1	9	3	9	3	1	9
C2	0.11	1	0.11	1	0.11	0.11	0.33
C3	0.33	9	1	9	1	0.33	9
C4	0.11	1	0.11	1	0.11	0.11	0.33
C5	0.33	9	1	9	1	0.33	9
C6	1	9	3	9	3	1	9
C7	0.11	3	0.11	3	0.11	0.11	1
Sum:	2.99	41	8.33	41	8.33	2.99	37.67

Table 35. The normalized matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	Weight (%)	Weight [W]
C1	0.33	0.22	0.36	0.22	0.36	0.33	0.24	29.49	0.29
C2	0.037	0.024	0.01	0.024	0.013	0.037	0.0088	2.26	0.02
C3	0.11	0.219	0.12	0.219	0.12	0.11	0.24	16.29	0.16
C4	0.037	0.024	0.013	0.024	0.01	0.04	0.01	2.26	0.02
C5	0.11	0.219	0.12	0.219	0.12	0.11	0.24	16.29	0.16
C6	0.33	0.219	0.36	0.219	0.36	0.33	0.24	29.49	0.29
C7	0.037	0.073	0.013	0.073	0.013	0.037	0.026	3.91	0.04

Consistency check:

Table 36. Consistency check tables

Determine the weight sums vector: [1]=[C][W]	Find the consistency vector: {Consis}=Dot Product[1].[1/W]
2.326245	3.390439
0.160019	44.20007
1.281449	6.139356
0.160019	44.20007

1.281449	6.139356
2.326245	3.390439
0.276577	25.58191

Calculate the average element, λ= 7.532798
Calculate the consistency Index (CI):

$$CI = \frac{\lambda - n}{n - 1} = 0.0888$$

Calculate the Consistency Ratio (CR):

$$CR = \frac{CI}{RC} = 0.067272$$

CR<0.10, so the degree of consistency is considered satisfactory.
The following table sums up the selected criteria for biomass technology and their weight:

Table 37. Selected criteria for onshore wind energy and their weight

ID	Criterion	Weight (%)
C1	Proximity to roads (in m)	29.49
C2	Proximity to transmission lines (in m)	2.26
C3	Population density	16.29
C4	Slope	2.26
C5	Elevation	16.29
C6	Land use and land cover	29.49
C7	Water availability	3.91

6. Case 6: Geothermal Energy

Table 38. Selected criteria among the experts' response

ID	Criterion name	Ranking of the experts
C1	Proximity to roads (in m)	0.857143
C2	Distance to rural communities	0.6
C3	Land use and land cover	1

Table 39. The pairwise matrix [C]

Criteria	C1	C2	C3
C1	1	5	0.33
C2	0.2	1	0.11
C3	3	9	1
Sum:	4.2	15	1.44

Table 40. The normalized matrix

Criteria	C1	C2	C3	Weight (%)	Weight [W]
C1	0.24	0.33	0.23	26.74	0.27
C2	0.04	0.066	0.08	6.37	0.06
C3	0.71	0.6	0.69	66.89	0.67

Consistency check:

Table 41. Consistency check tables

Determine the weight sums vector: [1]=[C][W]	Find the consistency vector: {Consis}=Dot Product[1].[1/W]
3.739726	3.025571
15.68966	3.005109
1.495071	3.056955

Calculate the average element, λ= 3.029211

Calculate the consistency Index (CI):

$$CI = \frac{\lambda - n}{n - 1} = 0.014606$$

Calculate the Consistency Ratio (CR):

$$CR = \frac{CI}{RC} = 0.025182$$

CR<0.10, so the degree of consistency is considered satisfactory.

The following table sums up the selected criteria for geothermal technology and their weight:

Table 42. Selected criteria for geothermal energy and their weight

ID	Criterion	Weight (%)
C1	Proximity to roads (in m)	26.74
C2	Distance to rural communities	6.37
C3	Land use and land cover	66.89

Discussion and Conclusion

The various criteria for selecting suitable sites for the different renewable energy resources have been identified, and based on experts' opinion selected criteria have been investigated for Lebanon.

AHP as a well-known decision making criteria was used to identify the weight of potential of resources. The scores and weight of solar, wind, geothermal and biomass potential for Lebanon were calculated.

The result of calculation weight will be used in the GIS environment; GIS enables generating a theoretical potential resources map based on overlapping solar energy, wind, biomass, and geothermal potential maps.

A result resource map will be made by combining the AHP and GIS to show the suitability site of renewable energy resources for the entire Lebanon, prioritizing renewable energy development.

CHAPTER VI

RESULTS BASED ON EXPERTS' FEEDBACK

This chapter presents the state-level results of a spatial analysis site selection for the renewable energy technologies installations in Lebanon based on expert feedback. It encompasses the output of solving the complex decision problems of allocating land suitability and producing the maps.

The Arc GIS 10.6.1 was used to apply the multi-criteria decision analysis. With its abilities to handle different kinds of topological, spatial, weather variation, GIS models offer a great advantage for the presented problem. Several steps were created using GIS models. First of all, data were collected according to the selected criteria interpreted by experts. Then, some data were digitized and others were modified and updated in order to create thematic maps for the criteria that influence the site selection process. All maps were projected on one coordinate system: WGS_1984_UTM_Zone_36N. Second of all, the data criteria maps were arranged following different selected range for each renewable energy technology. At the end, layers of these criteria setting were combined and weights, obtained from the multi-criteria decision making method, were assigned to the factor criteria layers. Suitable sites were selected and reclassified on a scale of 5 where 5 being the most important, after incorporating the various criteria.

Spatial suitability modeling with a GIS is increasingly used as a technique to identify potential locations for renewable energy generation. GIS may be a significant aid in collecting and organizing spatial data for the application of a location model.

In this case study, several steps were followed. First, spatial and other available data (population, road, hydrology, protected area, transmission lines, shoreline, major towns, and villages) were collected, and then various criteria maps were created. The slope and slope orientation/aspect were extracted from the digital elevation model (DEM) by applying spatial analysis from GIS software. The solar irradiation maps were obtained from SOLARGIS (www.solargis.com): Global Horizontal Irradiation (GHI) map and Direct Normal Irradiation (DNI) map were downloaded.

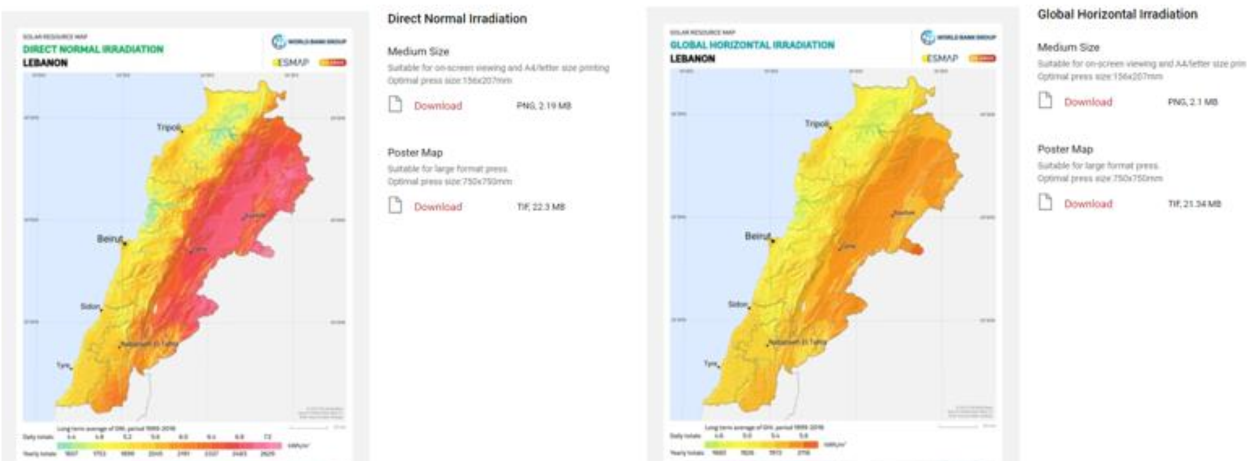


Figure 8. Direct Normal and Global Horizontal Irradiation maps downloaded from SOLARGIS

The wind power data were found in GLOBAL WIND ATLAS (www.globalwindatlas.info); a free web-based application developed to help policymakers, planners, and investors identify high-wind areas for wind power generation virtually anywhere in the world.

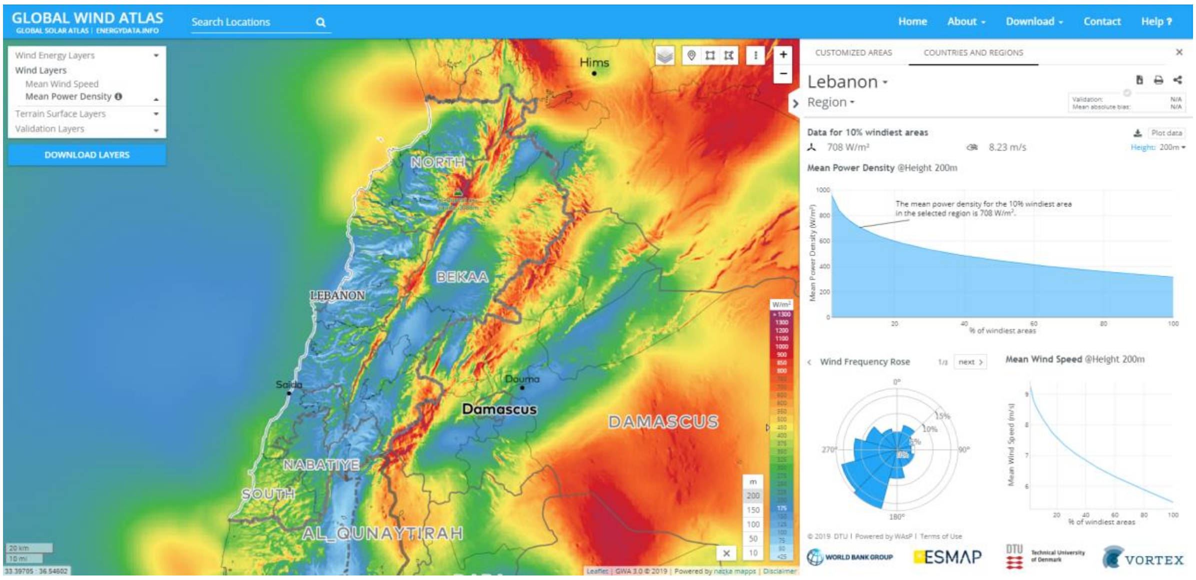


Figure 9. Mean power density map for Lebanon at height 200m

Second, maps were created following restrictions/ranges obtained from the questionnaire.

In this chapter, each renewable energy technology was treated separately following a consistent methodology and specified criteria and ranges.

A. GIS Analysis for Technology 1: Onshore Wind Energy

1. An Overview of Selected Criteria, Ranges and Weights

Table 43. Selected criteria, ranges and weights for the onshore wind energy technology

ID	Criteria	Range (median from questionnaire)	Weight (%)
C1	Wind power density	>260 W/m^2	37.17
C2	Proximity to roads (in m)	>500m and <10000m	12.50
C3	Proximity to transmission lines (in m)	>125m and <15000m	12.50
C4	Distance to shore	>1000m	3.74
C5	Proximity to urban areas	>500m and <10000m	12.50
C6	Distance to rural communities	>1000m	12.50
C7	Slope	Max 8.51°	3.74
C8	Elevation	<1500m	3.74
C9	Land use and land cover	1 km away from protected areas, water bodies and forests, 2.5 km away from airports. Preferred land: grassland and bare land	1.61

2. An Overview of the Methodology

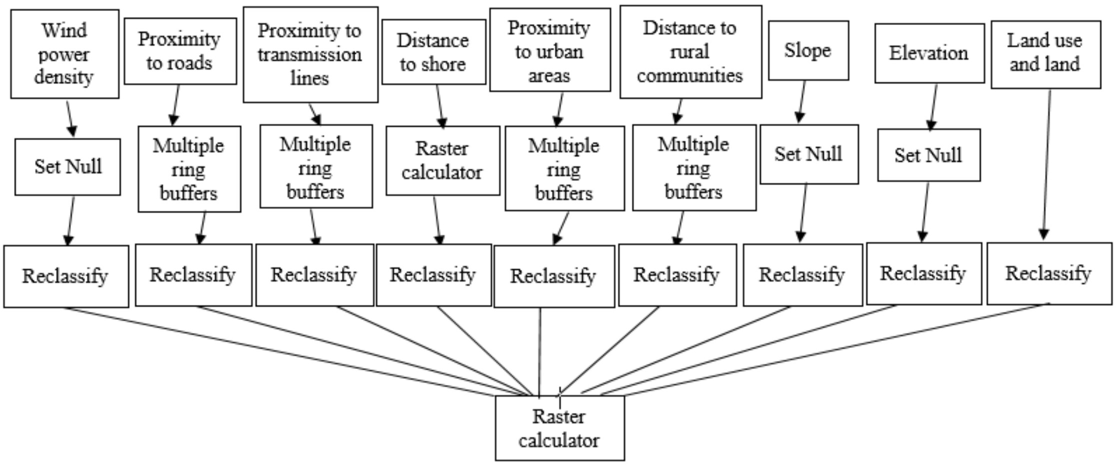


Figure 10. Methodology applied for technology 1: onshore wind energy

3. Maps and Ranges

The following factors were considered in the site selection for onshore wind farm: wind power density, proximity to roads, proximity to transmission lines, distance to shore, proximity to urban areas, distance to rural communities, slope, elevation and land use and land cover. Maps for each criterion were created based on a set of range.

a. Criterion 1: Wind Power Density

According to experts in Lebanon, wind power density must be more than 260 W/m^2. Using the Set Null tool in GIS, values less than 260 W/m^2 are returned to be NoData.

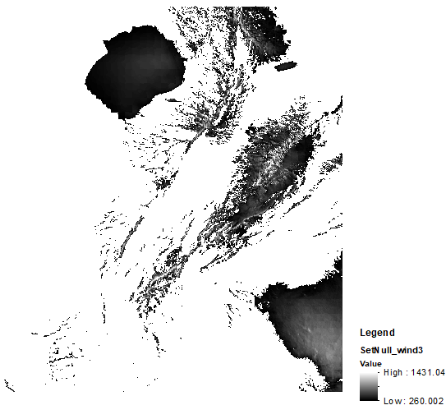


Figure 11. Wind power density map excluding values under 260 W/m^2

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
260 – 494	1
494 – 728	2
728 – 962	3
962 – 1196	4
1196 – 1431	5

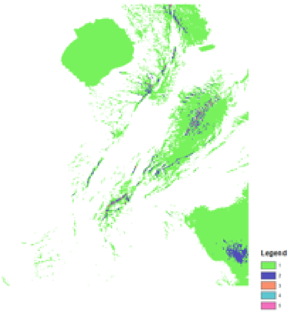


Figure 12. Reclassified table and map

b. Criterion 2: Proximity to Roads

The minimum distance from roads is 500 m and the maximum is 10 km. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 500m to 10km.

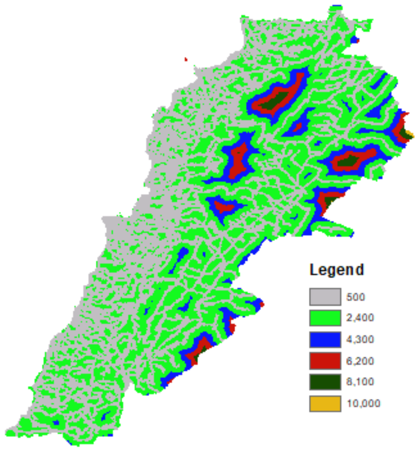


Figure 13. Multiple buffer zones for road map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near roads are considered the most important.

Old Values	New Values
0 – 500	NoData
500 – 2400	5
2400 – 4300	4
4300 – 6200	3
6200 – 8100	2
8100 – 10000	1

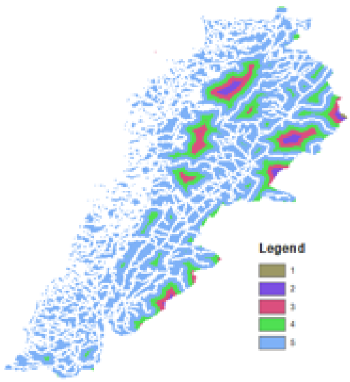


Figure 14. Reclassified table and map

c. <u>Criterion 3: Proximity to Transmission Lines</u>

The minimum distance from transmission lines is 125 m and the maximum is 15000 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 125 m to 15 km.

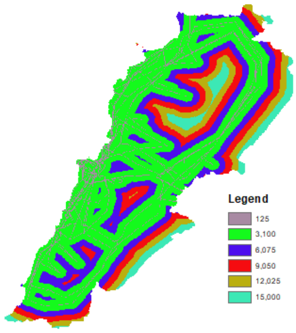


Figure 15. Multiple buffer zones for transmission lines map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near transmission lines are considered the most important.

Old Values	New Values
0 – 125	NoData
125 – 3100	5
3100 – 6075	4
6075 – 9050	3
9050 – 12025	2
12025 – 15000	1

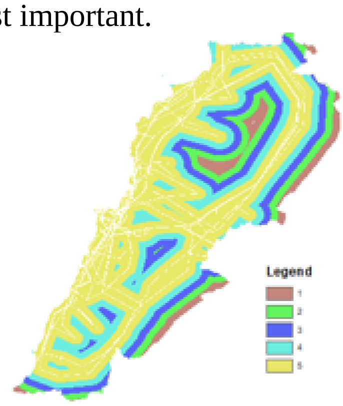


Figure 16. Reclassified table and map

d. <u>Criterion 4: Distance to Shoreline</u>

To install an onshore wind farm, a distance of 1 km away from the shoreline must be considered. The idea is to change everything more than 1 km away from shoreline to get a value of 1 and everything within 1 km gets a value of NoData. To do that, Raster Calculator tool in GIS was used.

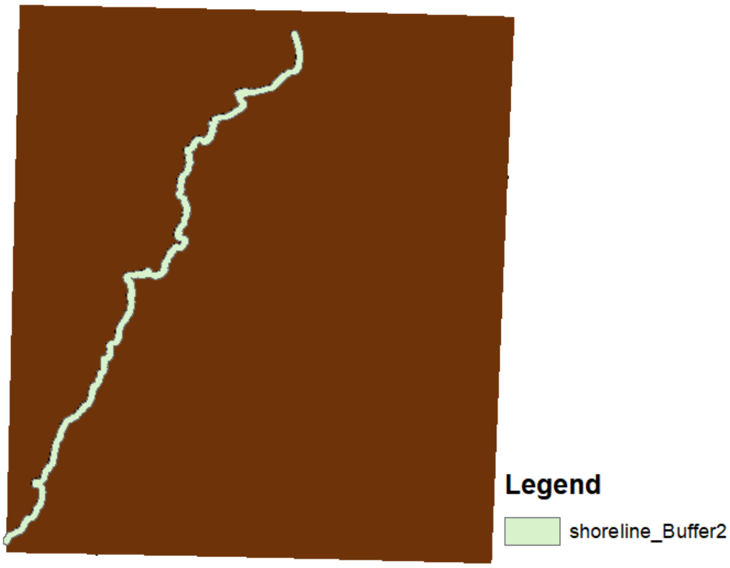


Figure 17. Shoreline map excluding a buffer zone of 1 km away from shoreline

e. <u>Criterion 5: Proximity to Urban Areas</u>

The minimum distance from urban areas is 500 m and the maximum is 30000 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 500 m to 30 km.

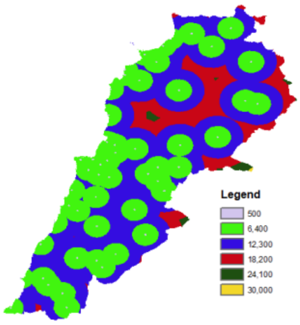


Figure 18. Multiple buffer zones for urban areas map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near cities are considered the most important.

Old Values	New Values
0 – 500	NoData
500 – 6400	5
6400 – 12300	4
12300 – 18200	3
18200 – 24100	2
24100 – 30000	1

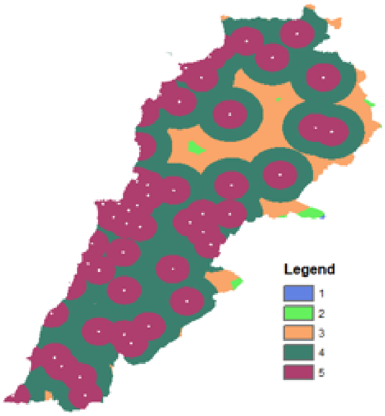


Figure 19. Reclassified table and map

f. <u>Criterion 6: Proximity to Rural Communities</u>

The minimum distance from rural communities is 1000 m and the maximum is 12000m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 1000 m to 12 km.

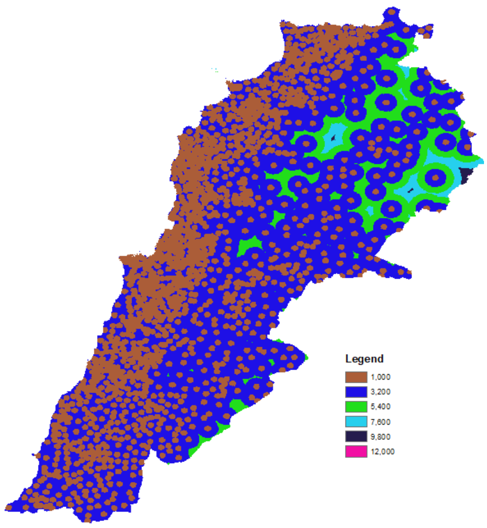


Figure 20. Multiple buffer zones for rural communities map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near cities are considered the most important.

Old Values	New Values
0 – 1000	NoData
1000 – 3200	5
3200 – 5400	4
5400 – 7600	3
7600 – 9800	2
9800 – 12000	1

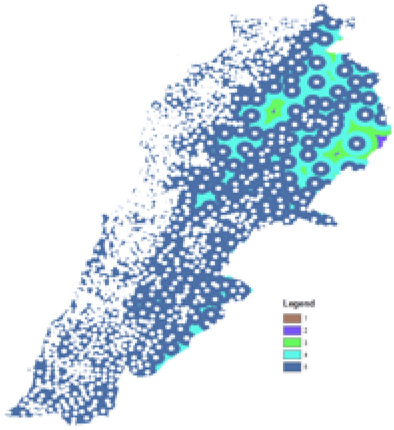


Figure 21. Reclassified table and map

g. Criterion 7: Slope

To install a wind farm, it is preferable to have a slope below 8.51°. For that, we used the Set Null tool in GIS to return values less than 8.51° to NoData.

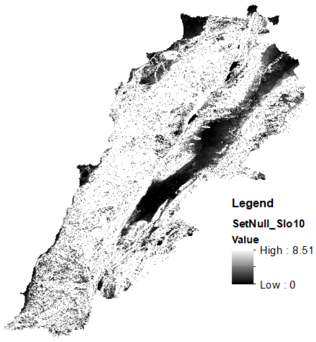


Figure 22. Slope map excluding slope below 8.51°

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
0 – 0.1702	5
0.1702 – 3.404	4
3.404 – 5.106	3
5.106 – 6.808	2
6.808 – 8.51	1

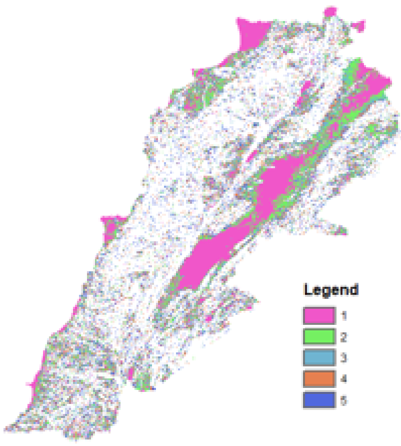


Figure 23. Reclassified table and map

h. <u>Criterion 8: Elevation</u>

Same process were repeated with the elevation criterion, where Set Null tool in GIS returns values more than 1500 to NoData.

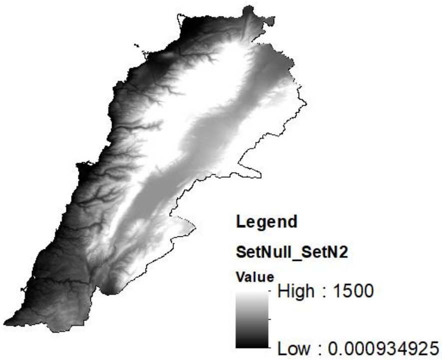


Figure 24. Elevation map excluding elevation values more than 1500 m

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
0 – 300	5
300 – 600	4
600 – 900	3
900 – 1200	2
1200 – 1500	1

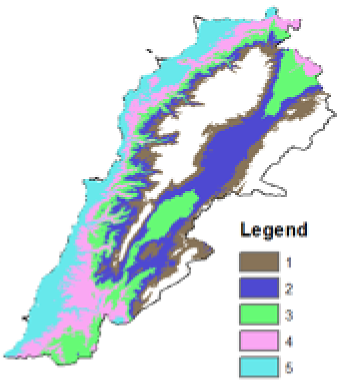


Figure 25. Reclassified table and map

i. <u>Criterion 9: Land Use and Land Cover</u>

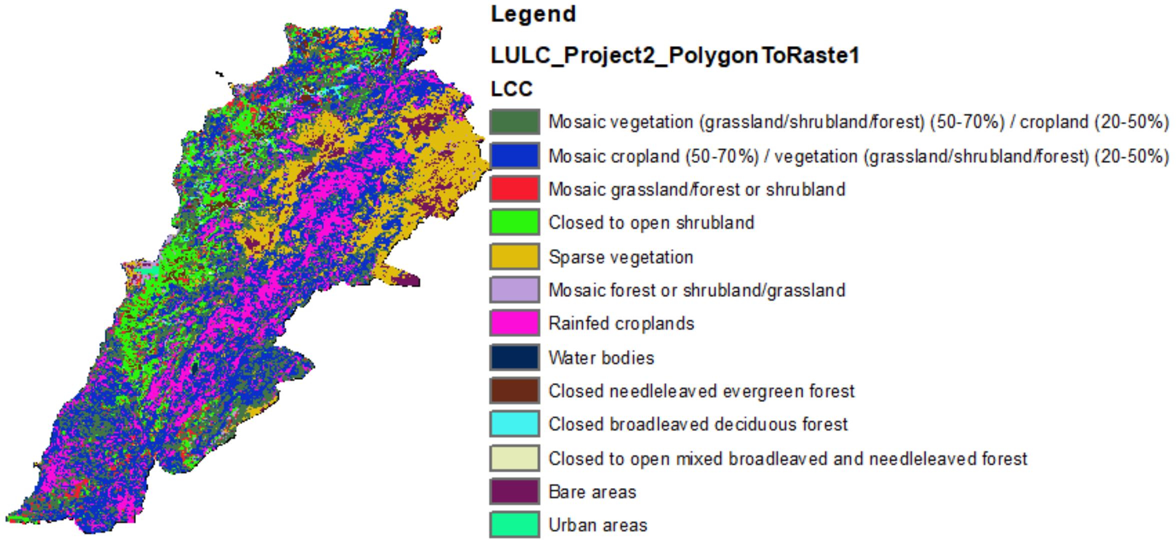


Figure 26. Land use and land cover map

The land use and land cover map was reclassified according to the following:

Old Values	New Values
Bare areas	5
Sparse vegetation	4
Vegetation, cropland, shrub land, forest, evergreen	3
Urban areas	2
Water Bodies	1

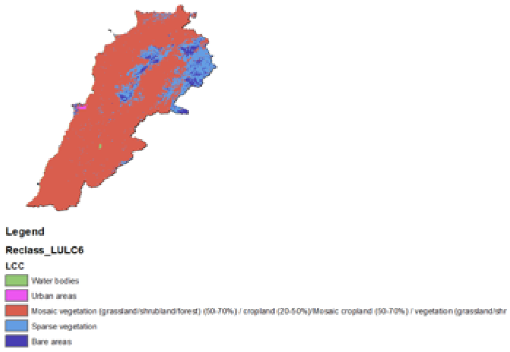


Figure 27. Reclassified table and map

4. Optimal Site Selection for Onshore Wind Energy Sites

After arranging the criteria maps, it is time to combine everything together to obtain the final map, specifically the suitable site to install onshore wind farms. For that, we will use the Map Algebra tool in GIS. We will sum the scores from all the layers and each score/criterion is multiplied by its weight (obtained from the multi-criteria decision making method, the AHP).

Here is the result:

Overall map=

"Onshore wind\Criterion 1: wind power density\Reclassified"*0.37+"Onshore wind\Criterion 2: proximity to road\Reclassified"*0.13+"Onshore wind\Criterion 3:

proximity to transmission lines\Reclassified"*0.13+"Onshore wind\Criterion 4: distance to shore\shoreline"*0.04+"Onshore wind\Criterion 5: distance to urban areas\Reclassified"*0.13+"Onshore wind\Criterion 6: distance to rural communities\Reclassified"*0.13+"Onshore wind\Criterion 7: slope\Reclassified"*0.04+"Onshore wind\Criterion 8: elevation\Reclassified"*0.04+"Onshore wind\Criterion 9: land use and land cover\Reclassified"*0.02

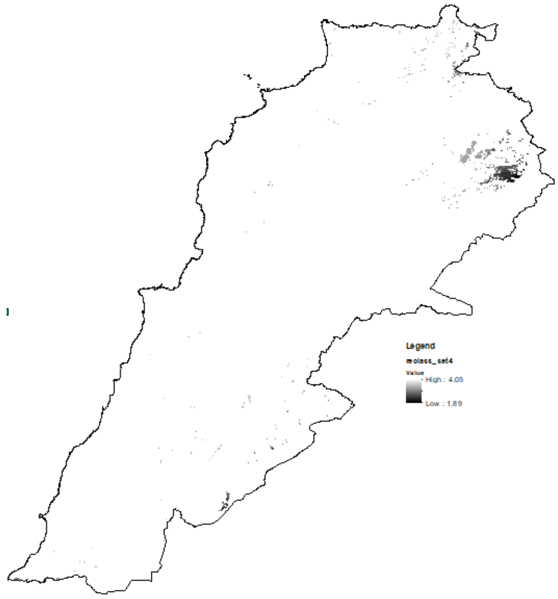


Figure 28. Optimal site location for onshore wind in Lebanon

B. GIS Analysis for Technology 2: Offshore Wind Energy

1. An Overview of Selected Criteria, Ranges and Weights

Table 44. Selected criteria, ranges and weights for the offshore wind energy technology

ID	Criteria	Range (median from questionnaire)	Weight (%)
C1	Wind power density	>300 W/m^2	72.35
C2	Slope	Max 11.31°	8.33
C3	Land use and land cover	1 km away from protected areas, water bodies and forests, 2.5 km away from airports. Preferred land: grassland and bare land	19.32

2. An Overview of the Methodology

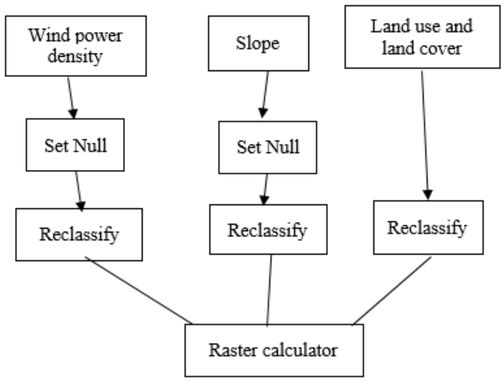


Figure 29. Methodology applied for technology 2: offshore wind energy

3. Maps and Ranges

The following factors were considered in the site selection for offshore wind farm: wind power density, slope and land use and land cover. Maps for each criterion were created based on a set of range.

Before analyzing each criterion map, it is to be noted that for implementation of wind-energy facilities in Lebanese waters, there were some practical constraints that deserve a brief mention even though they fall beyond the scope of this study. The Lebanese exclusive economic zone (EEZ) extends 200 nautical miles from the coast and, according to Lebanese legislation, there is a buffer area of 3 km in which economic activities like wind energy could not be allowed. It is also worthwhile to mention that water depth increases rapidly as we move from the coast into the sea, thus making floating wind turbines the best solution for any future wind farm.
Using GIS, we created these constraints: the exclusive economic zone and the buffer area of 3 km.

Figure 30. The constraints map

Using Joint tool in GIs, we selected the area where offshore wind turbines can be installed legally.

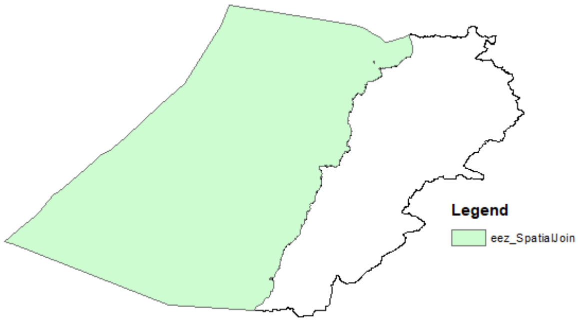


Figure 31. The selected area

a. <u>Criterion 1: Wind Power Density</u>

According to experts in Lebanon, wind power density must be more than 300 W/m2. Using the Set Null tool in GIS, values less than 260 W/m2 are returned to be NoData.

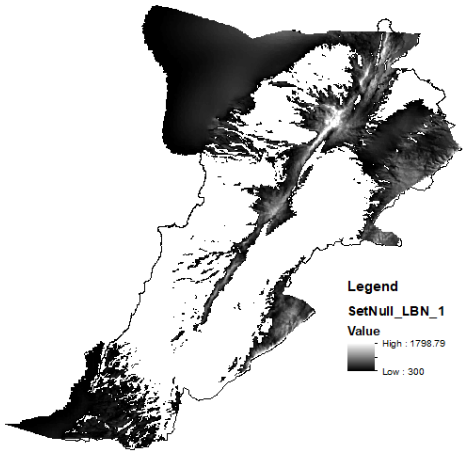


Figure 32. Wind power density map excluding values under 300 W/m^2

Using Clip tool, we selected the offshore region.

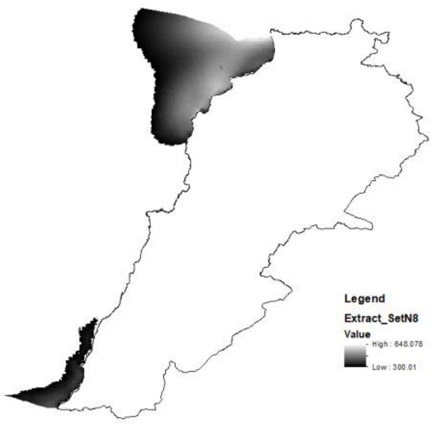


Figure 33. Wind power density map within the offshore region

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
300 – 369	1
369 – 439	2
439 – 508	3
508 – 578	4
578 – 648	5

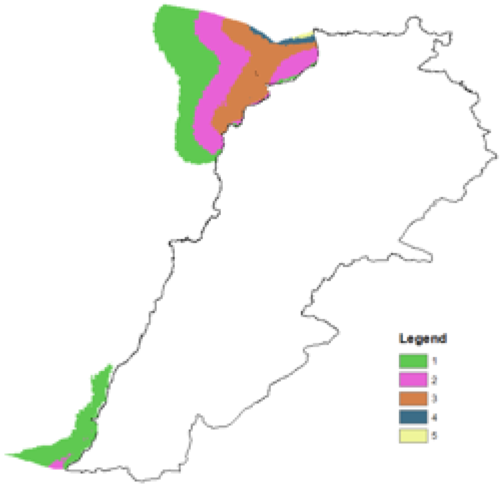


Figure 34. Reclassified table and map

b. Criterion 2: Slope

To install a wind farm, it is preferable to have a slope below 11.31°. For that, we used the Set Null tool in GIS to return values less than 11.31° to NoData.

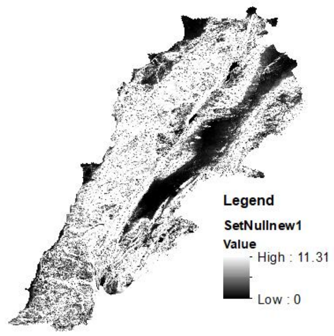


Figure 35. Slope map excluding slope below 11.31°

Using Clip tool, we selected the offshore region.

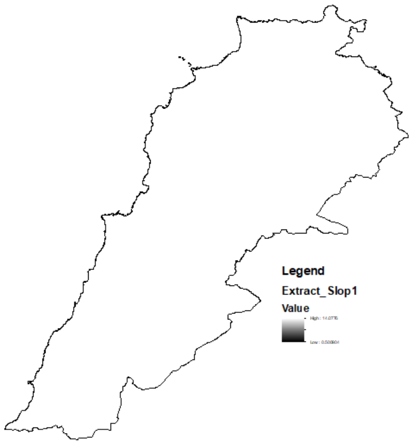


Figure 36. Slope map within the offshore region

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
0.5 – 3.2	5
3.2 – 5.9	4
5.9 – 8.6	3
8.6 – 11.4	2
11.4 – 14.1	1

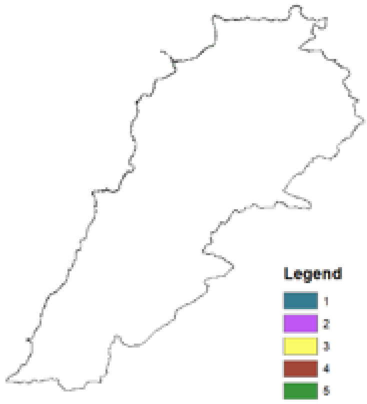


Figure 37. Reclassified table and map

c. <u>Criterion 3: Land Use and Land Cover</u>

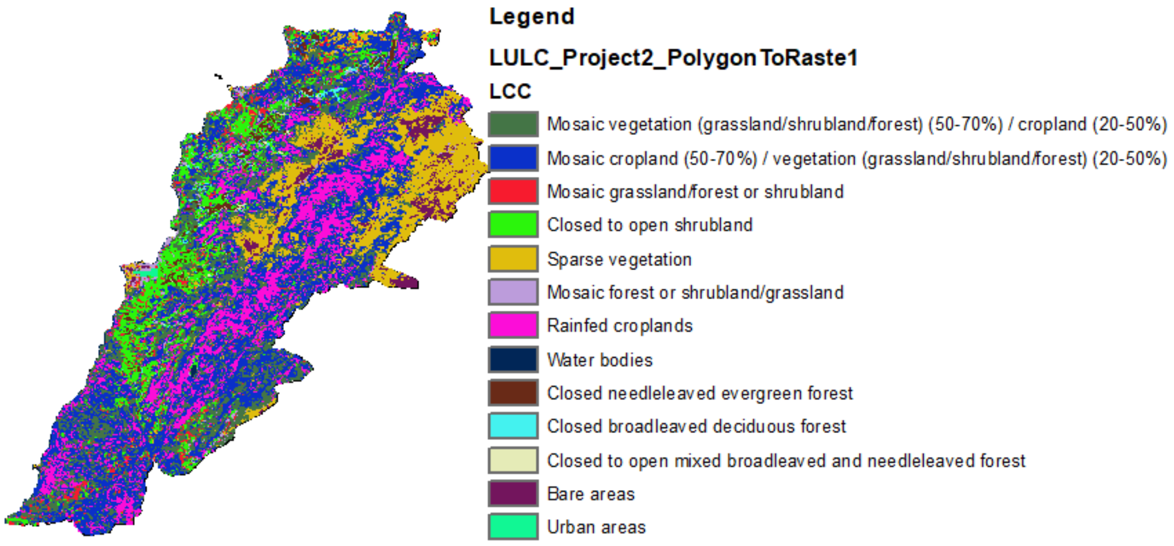


Figure 38. Land use and land cover map

Using Clip tool, we selected the offshore region.

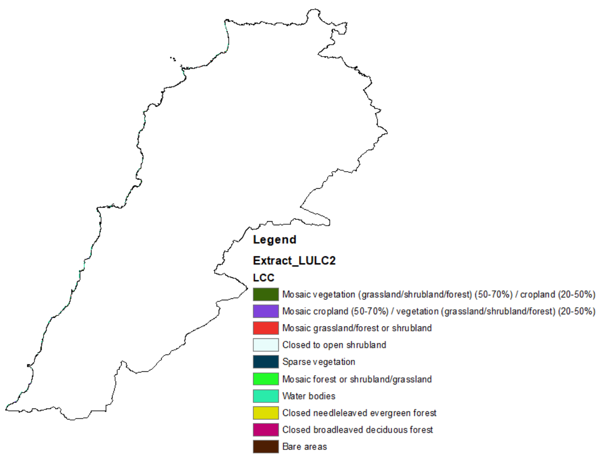


Figure 39. Land use and land cover map within the offshore region

The land use and land cover map was reclassified according to the following:

Old Values	New Values
Bare areas	5
Sparse vegetation	4
Vegetation, cropland, shrub land, forest, evergreen	3
Urban areas	2
Water Bodies	1

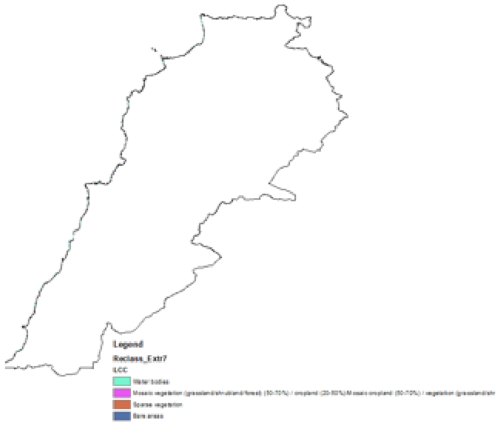


Figure 40. Reclassified table and map

4. Optimal Site Selection for Offshore Wind Energy Sites

After arranging the criteria maps, it is time to combine everything together to obtain the final map, specifically the suitable site to install onshore wind farms. For that, we will use the Map Algebra tool in GIS. We will sum the scores from all the layers and each score/criterion is multiplied by its weight (obtained from the multi-criteria decision making method, the AHP).

Here is the result:

Overall map=

"Offshore wind\Criterion 1: wind power density\Reclassified"*0.7235+"Offshore wind\Criterion 2: slope\Reclassified"*0.0833+"Offshore wind\Criterion 3: land use and land cover\Reclassified"*0.1931

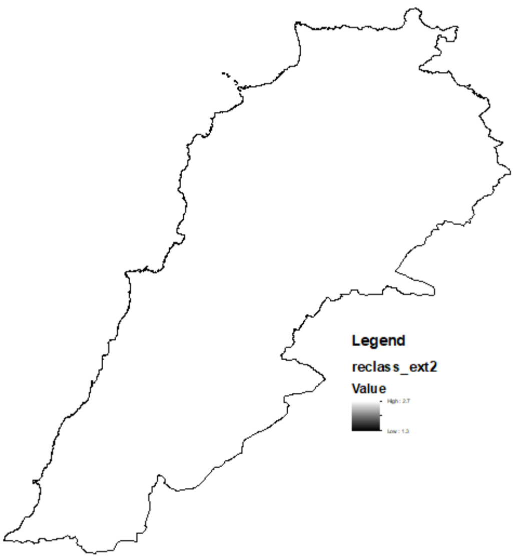


Figure 41. Optimal site location for offshore wind in Lebanon

C. GIS Analysis for Technology 3: CSP Energy

1. An Overview of Selected Criteria, Ranges and Weights

Table 45. Selected criteria, ranges and weights for the CSP technology

ID	Criteria	Range (median from questionnaire)	Weight (%)
C1	Solar irradiance	>1100 kWh/m^2 (DNI)	18.54
C2	Proximity to roads (in m)	>370m and <10000m	18.54
C3	Proximity to transmission lines (in m)	>240m and <22500m	18.54
C4	Distance to shore	>1000m	6.49
C5	Proximity to urban areas	Within 5250m, max: 30km	6.49
C6	Distance to rural communities	>1000m, max: 12km	3.85
C7	Slope	Max 2.1°	3.85
C8	Elevation	<1500m	18.54
C9	Land use and land cover	Preferred land: bare land	3.85
C10	Water availability	100m away from water	1.28

2. An Overview of the Methodology

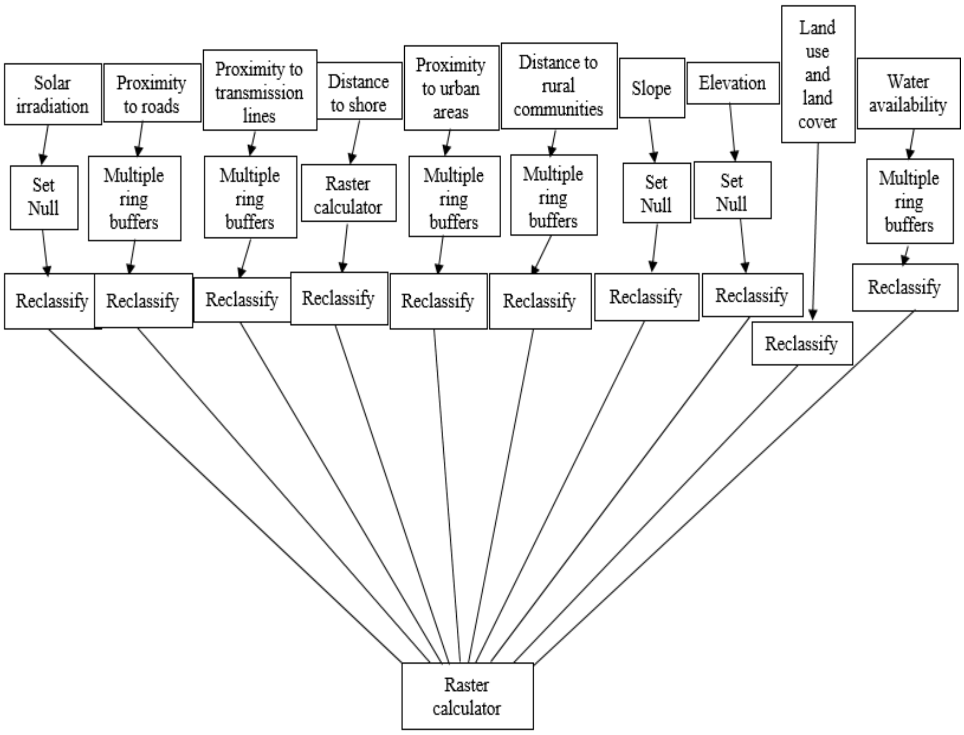


Figure 42. Methodology applied for technology 3: CSP energy

3. Maps and Ranges

The following factors were considered in the site selection for CSP farm: solar irradiation, proximity to roads, proximity to transmission lines, distance to shore, proximity to urban areas, distance to rural communities, slope, elevation, land use and land cover and water availability. Maps for each criterion were created based on a set of range.

a. <u>Criterion 1: Solar Irradiation, Direct Normal Irradiation DNI</u>

According to experts in Lebanon, direct normal irradiation must be more than 1100 kWh/m^2. Using the Set Null tool in GIS, values less than 1100 kWh/m^2 are returned to be NoData.

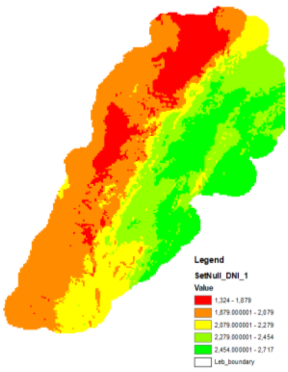


Figure 43. Direct Normal Irradiation map excluding values under 1100 KWh/m^2

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
1324 – 1879	1
1879 – 2079	2
2079 – 2279	3
2279 – 2454	4
2454 – 2717	5

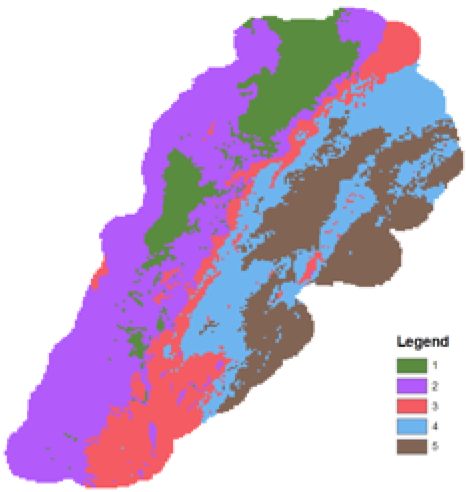


Figure 44. Reclassified table and map

b. Criterion 2: Proximity to Roads

The minimum distance from roads is 370 m and the maximum is 10 km. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 370m to 10km.

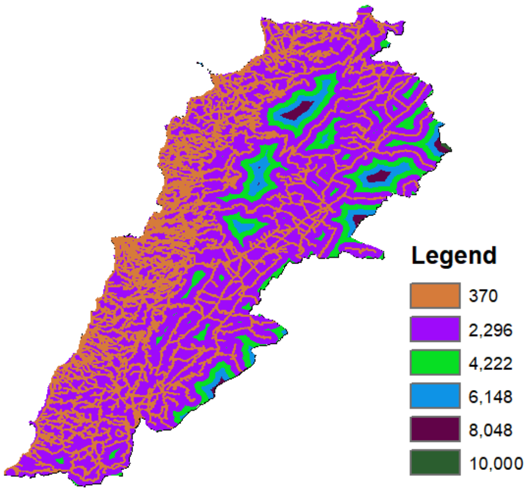


Figure 45. Multiple buffer zones for road map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near roads are considered the most important.

Old Values	New Values
0 – 370	NoData
370 – 2296	5
2296 – 4222	4
4222 – 6148	3
6148 – 8074	2
8074 – 10000	1

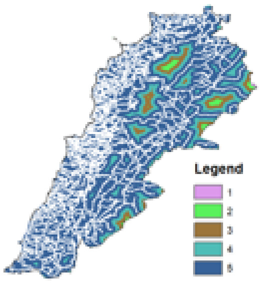


Figure 46. Reclassified table and map

c. Criterion 3: Proximity to Transmission Lines

The minimum distance from transmission lines is 240 m and the maximum is 22500 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 240 m to 22500 m.

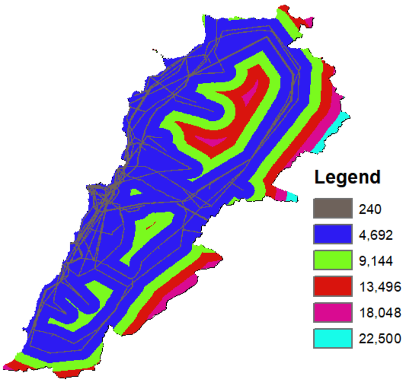


Figure 47. Multiple buffer zones for transmission lines map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near transmission lines are considered the most important.

Old Values	New Values
0 – 240	NoData
240 – 4692	5
4692 – 9144	4
9144 – 13496	3
13496 – 18048	2
18048 – 22500	1

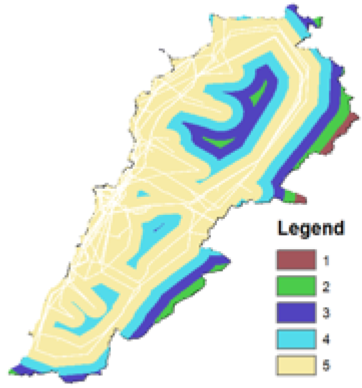


Figure 48. Reclassified table and map

d. Criterion 4: Distance to Shoreline

To install a CSP farm, a distance of 1 km away from the shoreline must be considered. The idea is to change everything more than 1 km away from shoreline to get a value of 1 and everything within 1 km gets a value of NoData. To do that, Raster Calculator tool in GIS was used.

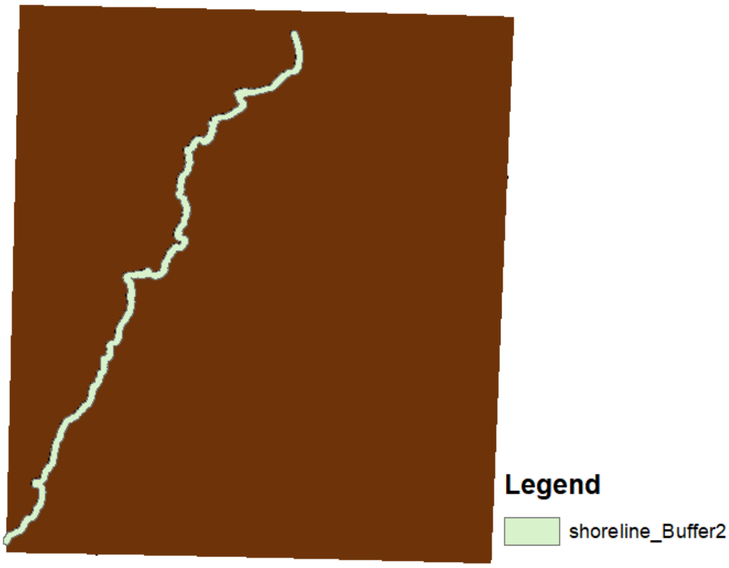


Figure 49. Shoreline map excluding a buffer zone of 1 km away from shoreline

e. <u>Criterion 5: Proximity to Urban Areas</u>

The minimum distance from urban areas is 5250 m and the maximum is 30000 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 5250 m to 30 km.

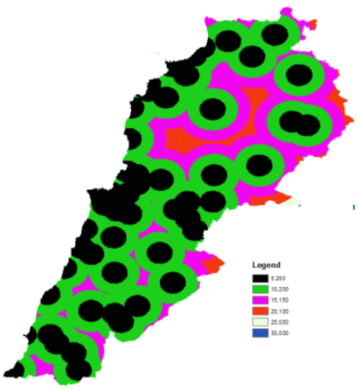


Figure 50. Multiple buffer zones for urban areas map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near cities are considered the most important.

Old Values	New Values
0 – 5250	NoData
5250 – 10200	5
10200 – 15150	4
15150 – 20100	3
20100 – 25050	2
25050 – 30000	1

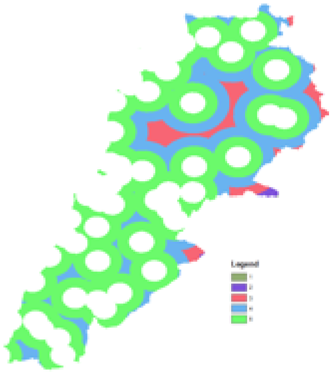


Figure 51. Reclassified table and map

f. Criterion 6: Proximity to Rural Communities

The minimum distance from rural communities is 1000 m and the maximum is 12000m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 1000 m to 12 km.

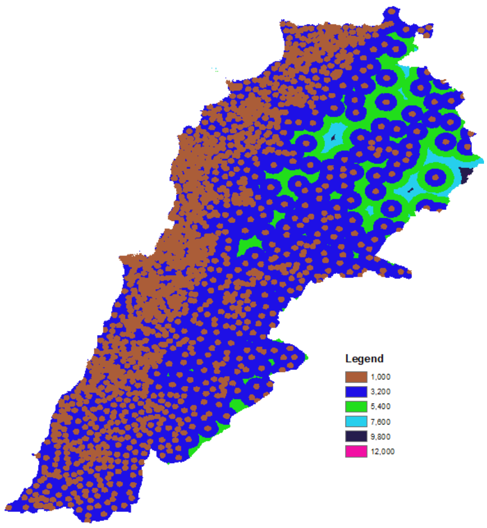


Figure 52. Multiple buffer zones for rural communities map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near cities are considered the most important.

Old Values	New Values
0 – 1000	NoData
1000 – 3200	5
3200 – 5400	4
5400 – 7600	3
7600 – 9800	2
9800 – 12000	1

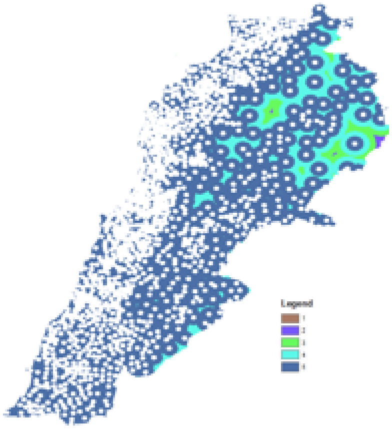


Figure 53. Reclassified table and map

g. <u>Criterion 7: Slope</u>

To install a CSP farm, it is preferable to have a slope below 2.1°. For that, we used the Set Null tool in GIS to return values less than 2.1° to NoData.

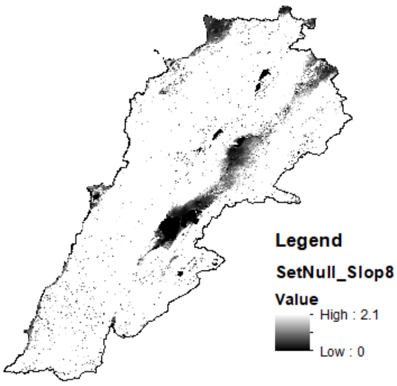


Figure 54. Slope map excluding slope below 2.1°

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
0 – 0.42	5
0.42 – 0.84	4
0.84 – 1.26	3
1.26 – 1.68	2
1.68 – 2.1	1

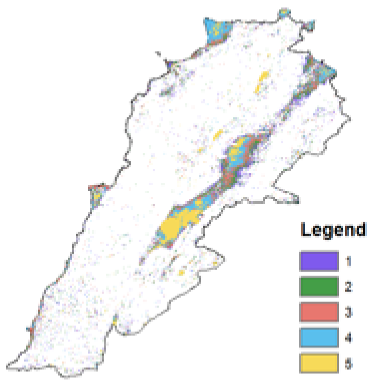


Figure 55. Reclassified table and map

h. <u>Criterion 8: Elevation</u>

Same process were repeated with the elevation criterion, where Set Null tool in GIS returns values more than 1500 to NoData.

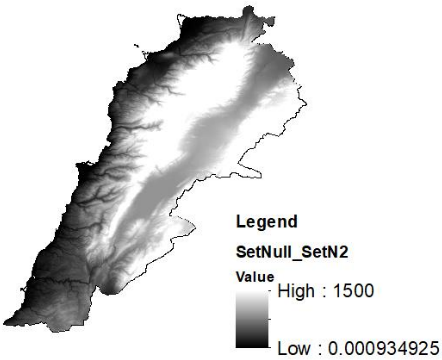


Figure 56. Elevation map excluding elevation values more than 1500 m

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
0 – 300	5
300 – 600	4
600 – 900	3
900 – 1200	2
1200 – 1500	1

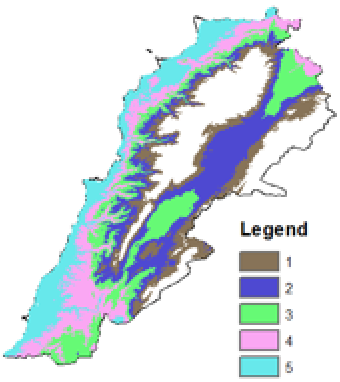


Figure 57. Reclassified table and map

i. <u>Criterion 9: Land Use and Land Cover</u>

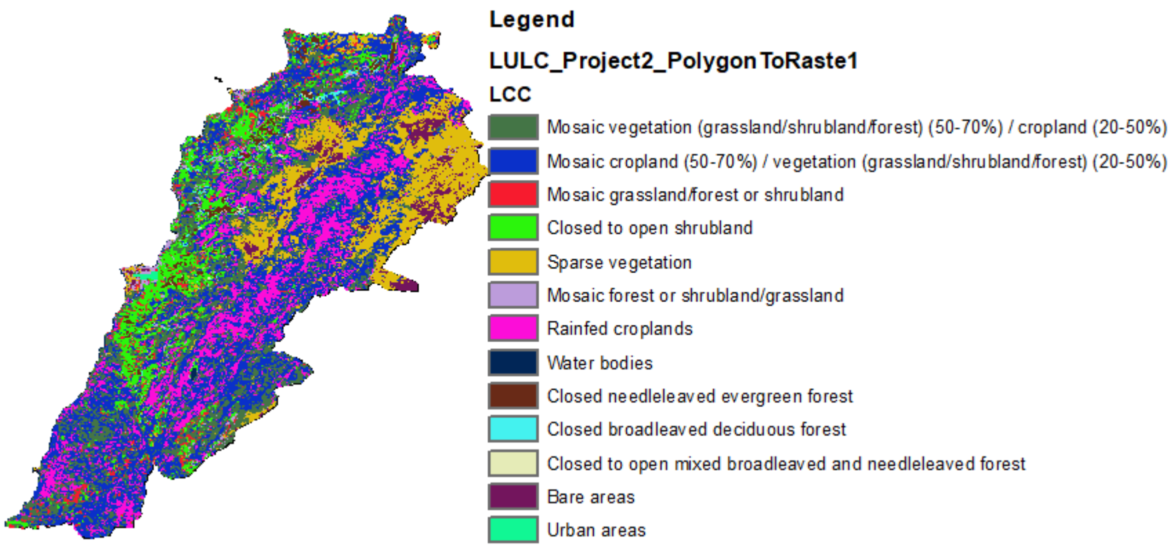


Figure 58. Land use and land cover map

The land use and land cover map was reclassified according to the following:

Old Values	New Values
Bare areas	5
Sparse vegetation	4
Vegetation, cropland, shrub land, forest, evergreen	3
Urban areas	2
Water Bodies	1

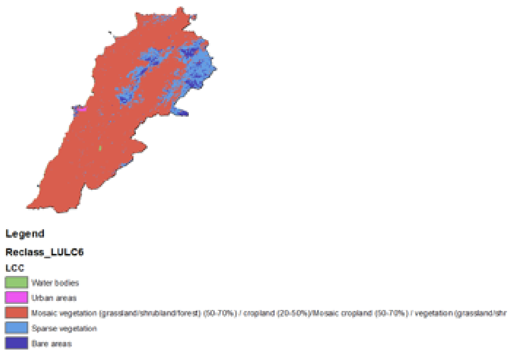


Figure 59. Reclassified table and map

j. <u>Criterion 10: Water Availability</u>

The minimum distance from water is 100 m and the maximum is 10 km. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 100m to 10km.

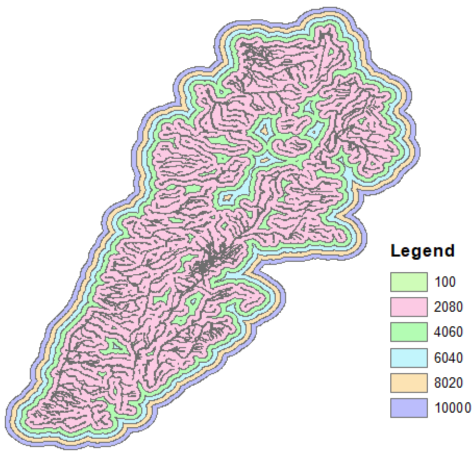


Figure 60. Multiple buffer zones for water availability map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near roads are considered the most important.

Old Values	New Values
0 – 100	NoData
1000 – 2080	5
2080 – 4060	4
4060 – 6040	3
6040 – 8020	2
8020 – 10000	1

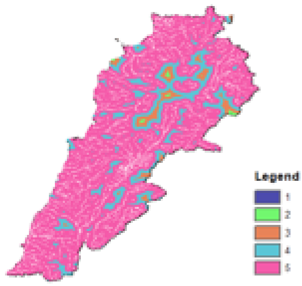


Figure 61. Reclassified table and map

4. Optimal Site Selection for CSP Energy Sites

After arranging the criteria maps, it is time to combine everything together to obtain the final map, specifically the suitable site to install CSP farms. For that, we will use the Map Algebra tool in GIS. We will sum the scores from all the layers and each score/criterion is multiplied by its weight (obtained from the multi-criteria decision making method, the AHP).

Here is the result:

Overall map=

"CSP\criterion 1: DNI\Reclassification"*0.19+"CSP\criterion 2: proximity to road\Reclassification"*0.19+"CSP\criterion 3: proximity to transmission line\Reclassification"*0.19+"PV\Criterion 4: distance to shore\shoreline"*0.065+"CSP\criterion 5: proximity to urban areas\Reclassification"*0.065+"CSP\criterion 6: proximity to rural communities\Reclassification"*0.04+"CSP\criterion 7: slope\Reclassification"*0.04+"PV\Criterion 8:

elevation\Reclassification"*0.19+"PV\Criterion 10: land use and land cover\Reclassification"*0.04+"CSP\criterion 10: water availability\Reclassification"*0.013

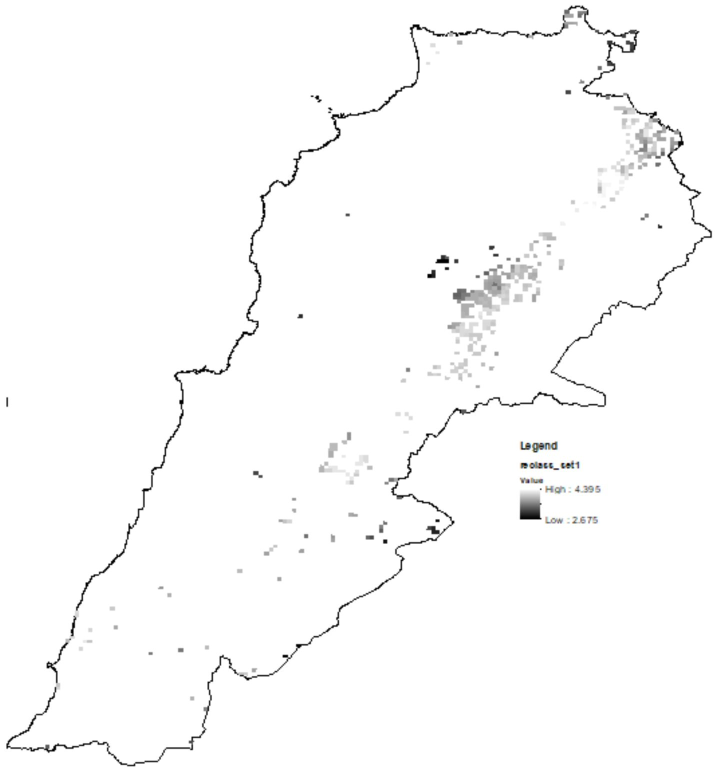


Figure 62. Optimal site location for CSP technology in Lebanon

D. GIS Analysis for Technology 4: PV Energy

1. An Overview of Selected Criteria, Ranges and Weights

Table 46. Selected criteria, ranges and weights for the PV technology

ID	Criteria	Range (median from questionnaire)	Weight (%)
C1	Solar irradiance	>1700 kWh/m^2 (DNI)	14.47
C2	Proximity to roads (in m)	>145m and <10000m	14.47
C3	Proximity to transmission lines (in m)	>240m and <20000m	14.47
C4	Distance to shore	>1000m	3.84
C5	Proximity to urban areas	>750m and <30000m	4.63
C6	Distance to rural communities	>500m and <12000m	1.62
C7	Slope	Max 26.765°	14.47
C8	Elevation	<1500m	14.47
C9	Aspect	South	14.47
C10	Land use and land cover	Preferred land: bare land	3.11

2. An Overview of the Methodology

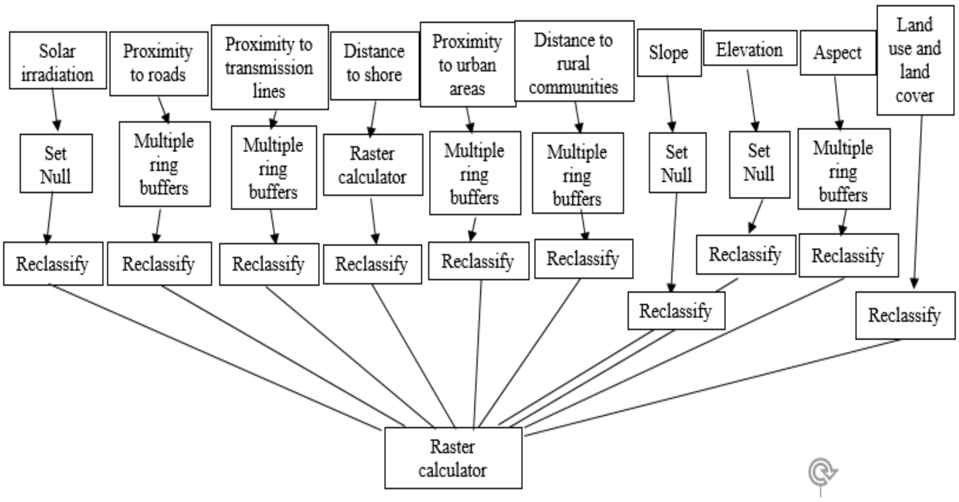


Figure 63. Methodology applied for technology 4: PV energy

3. Maps and Ranges

The following factors were considered in the site selection for PV farm: solar irradiation, proximity to roads, proximity to transmission lines, distance to shore, proximity to urban areas, distance to rural communities, slope, elevation, aspect and land use and land cover. Maps for each criterion were created based on a set of ranges.

a. Criterion 1: Solar Irradiation, Global Horizontal Irradiation GHI

According to experts in Lebanon, direct normal irradiation must be more than 1700 kWh/m^2. Using the Set Null tool in GIS, values less than 1700 kWh/m^2 are returned to be NoData.

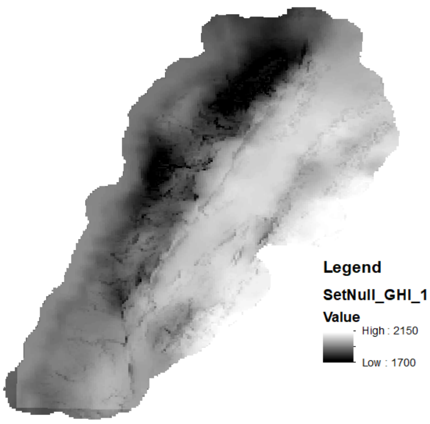


Figure 64. Global Horizontal Irradiation map excluding values under 1700 KWh/m^2

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
1700 – 1790	1
1790 – 1880	2
1880 – 1970	3
1970 – 2060	4
2060 – 2150	5

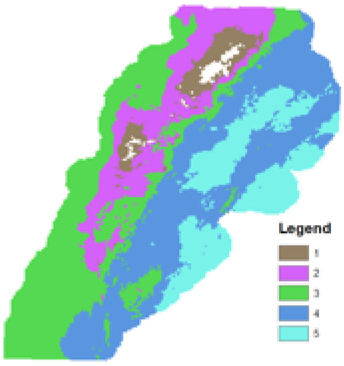


Figure 65. Reclassified table and map

b. Criterion 2: Proximity to Roads

The minimum distance from roads is 145 m and the maximum is 10 km. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 145m to 10km.

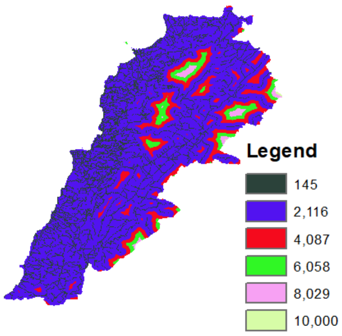


Figure 66. Multiple buffer zones for road map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near roads are considered the most important.

Old Values	New Values
0 – 145	NoData
145 – 2116	5
2116 – 4087	4
4087 – 6058	3
6058 – 8029	2
8029 – 10000	1

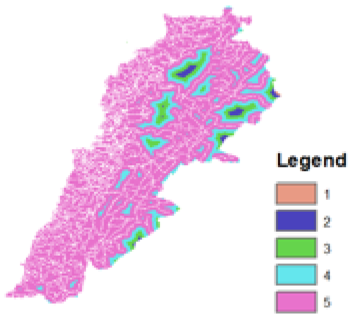


Figure 67. Reclassified table and map

c. <u>Criterion 3: Proximity to Transmission Lines</u>

The minimum distance from transmission lines is 240 m and the maximum is 20000 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 240 m to 20000 m.

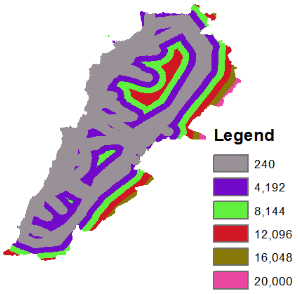


Figure 68. Multiple buffer zones for transmission lines map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near transmission lines are considered the most important.

Old Values	New Values
0 – 240	NoData
240 – 4192	5
4192 – 8144	4
8144 – 12096	3
12096 – 16048	2
16048 – 20000	1

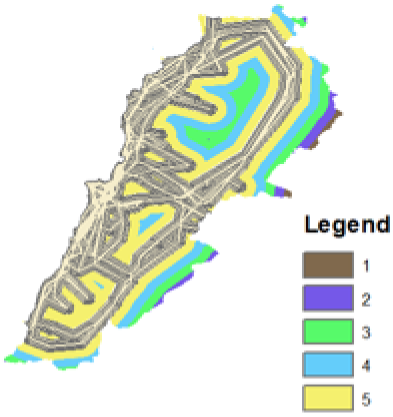


Figure 69. Reclassified table and map

d. <u>Criterion 4: Distance to Shoreline</u>

To install a PV farm, a distance of 1 km away from the shoreline must be considered. The idea is to change everything more than 1 km away from shoreline to get a value of 1 and everything within 1 km gets a value of NoData. To do that, Raster Calculator tool in GIS was used.

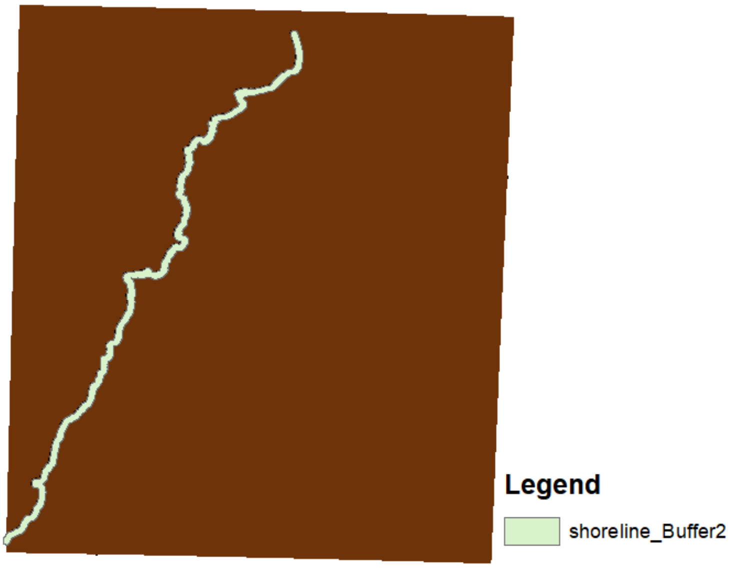


Figure 70. Shoreline map excluding a buffer zone of 1 km away from shoreline

e. <u>Criterion 5: Proximity to Urban Areas</u>

The minimum distance from urban areas is 750 m and the maximum is 30000 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 750 m to 30 km.

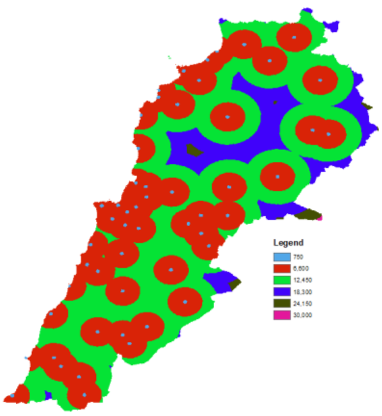


Figure 71. Multiple buffer zones for urban areas map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near cities are considered the most important.

Old Values	New Values
0 – 750	NoData
750 – 6600	5
6600 – 12450	4
12450 – 18300	3
18300 – 24150	2
24150 – 30000	1

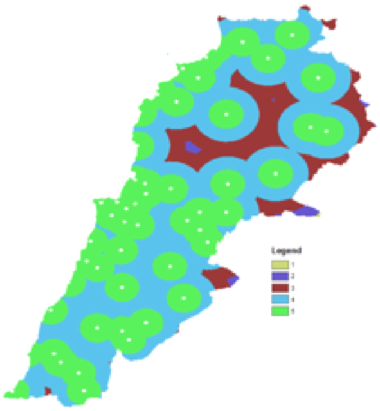


Figure 72. Reclassified table and map

f. <u>Criterion 6: Proximity to Rural Communities</u>

The minimum distance from rural communities is 500 m and the maximum is 12000m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 500 m to 12 km.

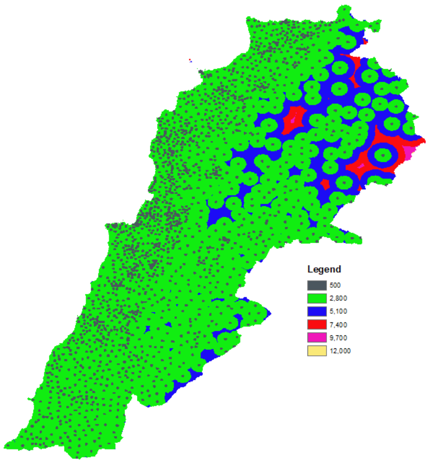


Figure 73. Multiple buffer zones for rural communities map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near cities are considered the most important.

-

Old Values	New Values
0 – 500	NoData
500 – 2800	5
2800 – 5100	4
5100 – 7400	3
7400 – 9700	2
9700 – 12000	1

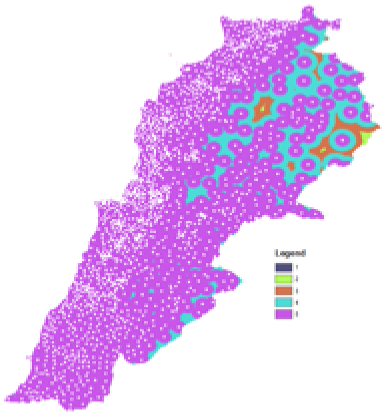


Figure 74. Reclassified table and map

g. <u>Criterion 7: Slope</u>

To install a PV farm, it is preferable to have a slope below 26.76°. For that, we used the Set Null tool in GIS to return values less than 26.76° to NoData.

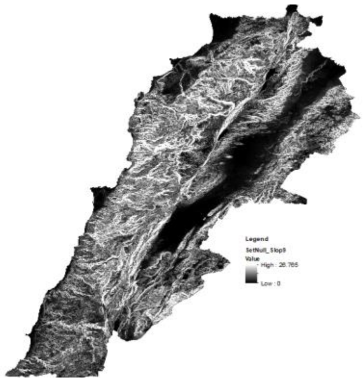


Figure 75. Slope map excluding slope below 26.76°

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
0 – 5.353	5
5.353 – 10.706	4
10.706 – 16.059	3
16.059 – 21.412	2
21.412 – 26.765	1

Figure 76. Reclassified table and map

h. <u>Criterion 8: Elevation</u>

Same process were repeated with the elevation criterion, where Set Null tool in GIS returns values more than 1500 to NoData.

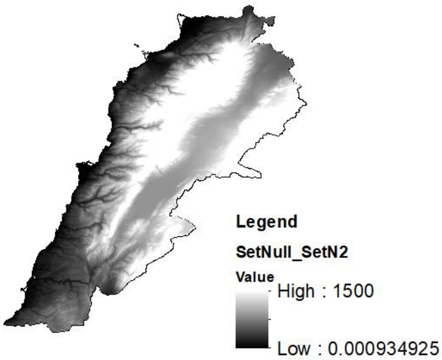


Figure 77. Elevation map excluding elevation values more than 1500 m

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
0 – 300	5
300 – 600	4
600 – 900	3
900 – 1200	2
1200 – 1500	1

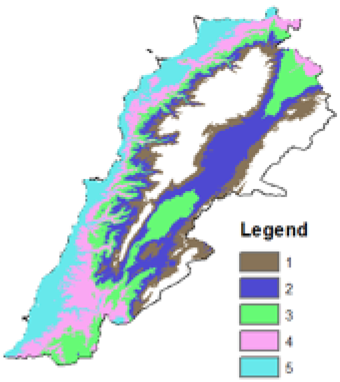


Figure 78. Reclassified table and map

i. <u>Criterion 9: Aspect</u>

Aspect/slope direction were generated from surface/aspect tool.

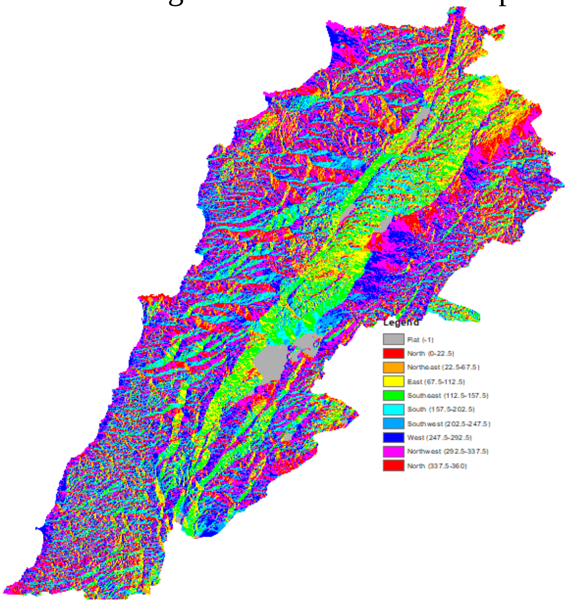


Figure 79. Aspect map

Flat areas or mild steep slopes will help to avoid the high construction cost required in high slope areas. Flat terrain is essential for large-scale PV farms; as such flat aspect (-1) is the most preferable and we assign 5 as value. A south-facing slope is an ideal orientation for solar farm sites; that is why 4 is assigned as a value for this aspect.

Old Values	New Values
Flat (-1)	5
South (157.5 – 202.5)	4
Southeast (112.5 – 157.5)	3
Southwest (202.5 – 247.5)	2

Figure 80. Reclassified table and map

j. Criterion 9: Land Use and Land Cover

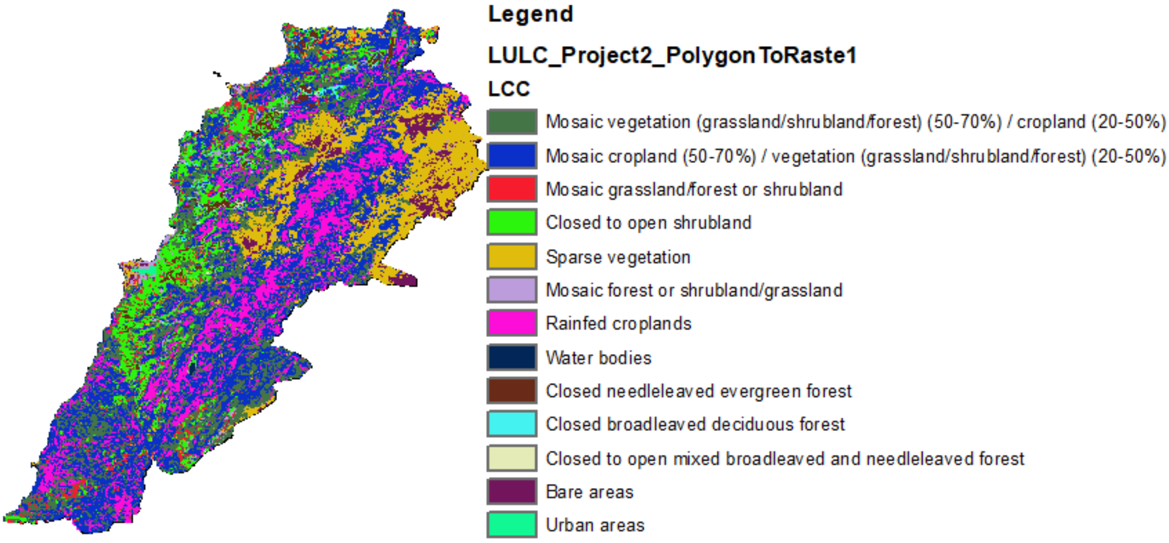


Figure 81. Land use and land cover map

The land use and land cover map was reclassified according to the following:

Old Values	New Values
Bare areas	5
Sparse vegetation	4
Vegetation, cropland, shrub land, forest, evergreen	3
Urban areas	2
Water Bodies	1

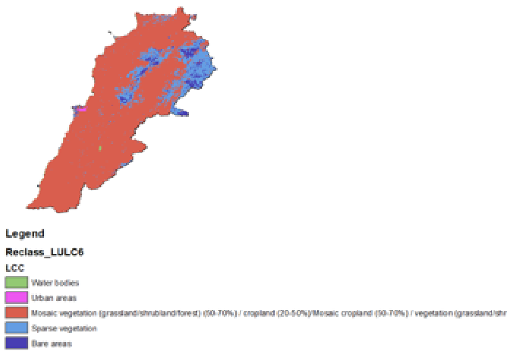


Figure 82. Reclassified table and map

4. Optimal Site Selection for PV Energy Sites

After arranging the criteria maps, it is time to combine everything together to obtain the final map, specifically the suitable site to install PV farms. For that, we will use the Map Algebra tool in GIS. We will sum the scores from all the layers and each score/criterion is multiplied by its weight (obtained from the multi-criteria decision making method, the AHP).

Here is the result:

Overall map=

"PV\criterion 1: GHI\Reclassification"*0.145+"PV\criterion 2: proximity to road\Reclassification"*0.145+"PV\criterion 3: proximity to transmission line\Reclassification"*0.145+"PV\Criterion 4: distance to shore\shoreline"*0.04+"PV\criterion 5: proximity to urban areas\Reclassification"*0.05+"PV\criterion 6: proximity to rural communities\Reclassification"*0.02+"PV\criterion 7: slope\Reclassification"*0.145+"PV\Criterion 8: elevation\Reclassification"*0.145+"PV\criterion 9: aspect\Reclassification"*0.145+ "PV\Criterion 10: land use and land cover\Reclassification"*0.03

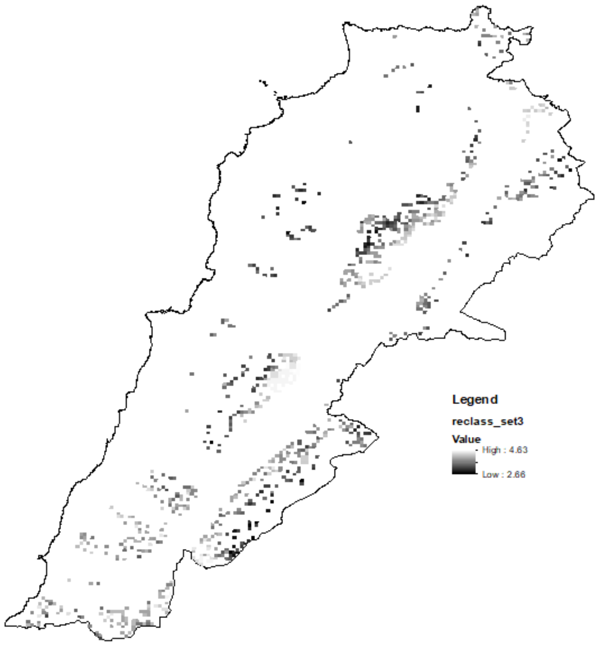


Figure 83. Optimal site location for PV technology in Lebanon

E. GIS Analysis for Technology 5: Biomass Energy

1. An Overview of Selected Criteria, Ranges and Weights

Table 47. Selected criteria, ranges and weights for the Biomass technology

ID	Criteria	Range (median from questionnaire)	Weight (%)
C1	Proximity to roads (in m)	>370m and <10000m	29.49
C2	Proximity to transmission lines (in m)	>240m and <22500m	2.26
C3	Population density	Within 1000m from population center (from the literature review)	16.29
C4	Slope	Max 8.53° (from the literature review)	2.26
C5	Elevation	2000m max	16.29
C6	Land use and land cover	500m near vegetation, agricultural zones and farming	29.49
C7	Water availability	100m away from water	3.91

2. An Overview of the Methodology

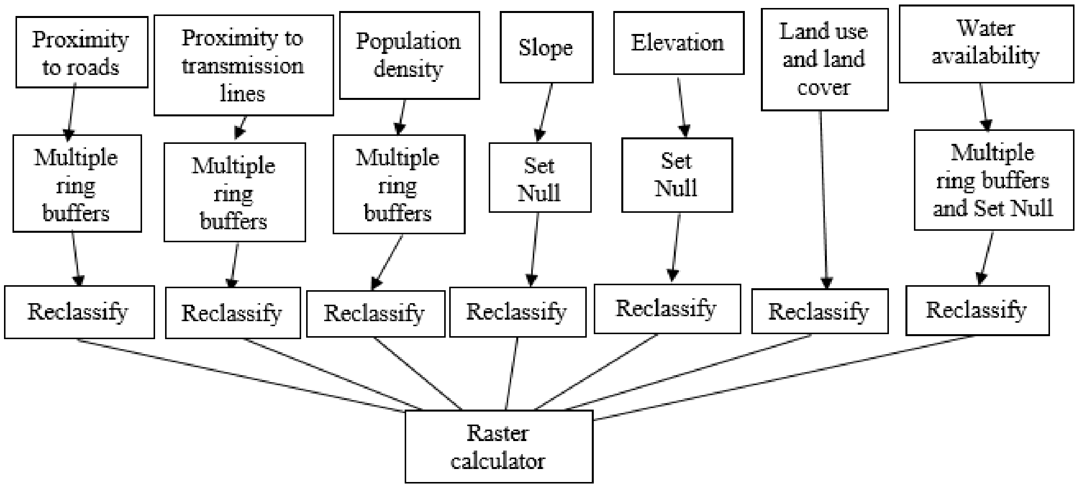


Figure 84. Methodology applied for technology 5: biomass energy

3. Maps and Ranges

The following factors were considered in the site selection for biomass farm: proximity to roads, proximity to transmission lines, population density, slope, elevation, land use land cover, and water availability. Maps for each criterion were created based on a set of range.

a. Criterion 1: Proximity to Roads

The minimum distance from roads is 300 m and the maximum is 10 km. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 300m to 10km.

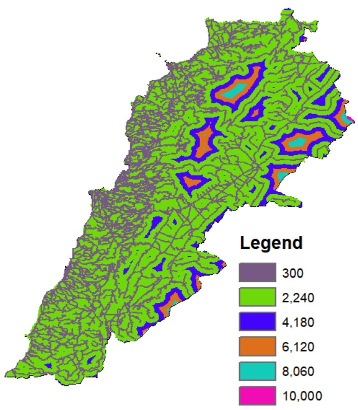


Figure 85. Multiple buffer zones for road map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near roads are considered the most important.

Old Values	New Values
0 – 300	NoData
300 – 2240	5
2240 – 4180	4
4180 – 6120	3
6120 – 8060	2
8060 – 10000	1

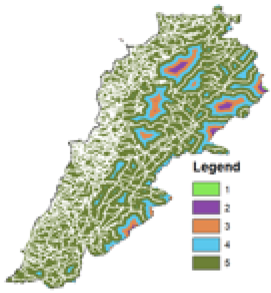


Figure 86. Reclassified table and map

b. Criterion 2: Proximity to Transmission Lines

The minimum distance from transmission lines is 240 m and the maximum is 22500 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 240 m to 22500 m.

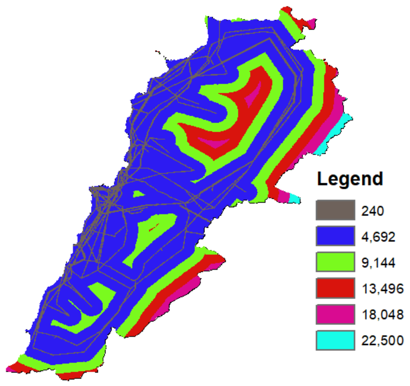


Figure 87. Multiple buffer zones for transmission lines map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near transmission lines are considered the most important.

Old Values	New Values
0 – 240	NoData
240 – 4692	5
4692 – 9144	4
9144 – 13496	3
13496 – 18048	2
18048 – 22500	1

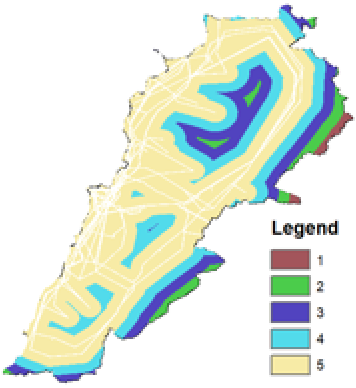


Figure 88. Reclassified table and map

c. <u>Criterion 3: Population Density</u>

The minimum distance from moderate population density is 1000 m and the maximum is 20000 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 1000 m to 20 km.

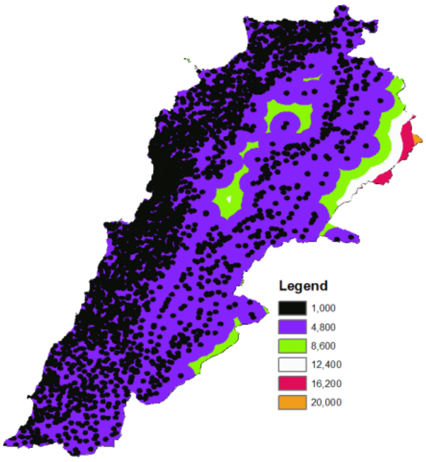


Figure 89. Multiple buffer zones for population density

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near cities are considered the most important.

Old Values	New Values
0 – 1000	NoData
1000 – 4800	5
4800 – 8600	4
8600 – 12400	3
12400 – 16200	2
16200 – 20000	1

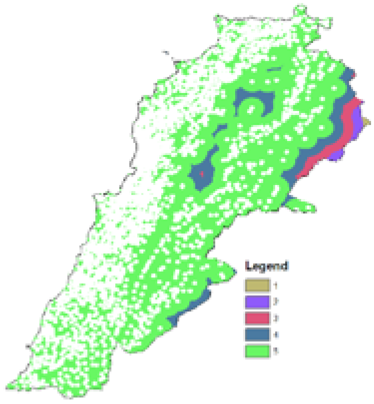


Figure 90. Reclassification table and map

d. <u>Criterion 4: Slope</u>

To install a biomass power plant, it is preferable to have a slope below 8.53°. For that, we used the Set Null tool in GIS to return values less than 8.53° to NoData.

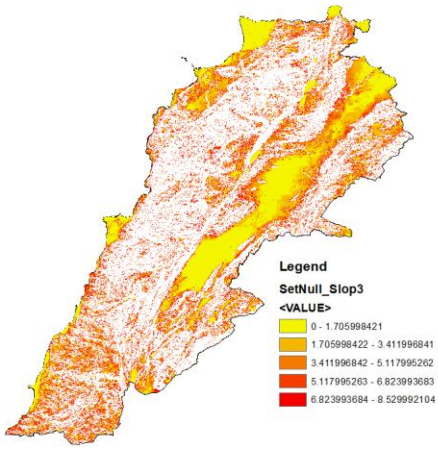


Figure 91. Slope map excluding slope below 8.53°

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
0 – 1.706	5
1.706 – 3.412	4
3.412 – 5.118	3
5.118 – 6.824	2
6.824 – 8.53	1

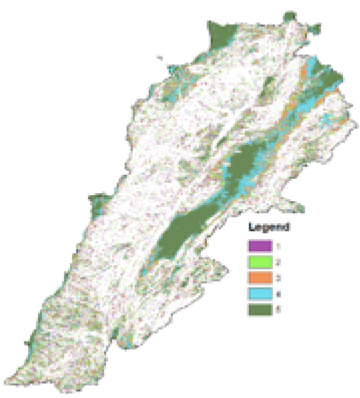


Figure 92. Reclassified table and map

e. <u>Criterion 8: Elevation</u>

Same process were repeated with the elevation criterion, where Set Null tool in GIS returns values more than 2000 to NoData.

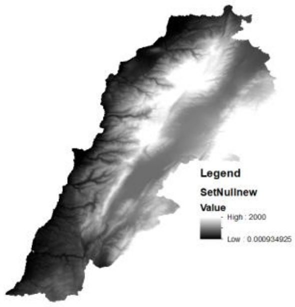


Figure 93. Elevation map excluding elevation values more than 2000 m

Then, using Reclassify tool in GIS, we arranged values into classes from 1 to 5, 5 being the most preferable.

Old Values	New Values
0 – 400	5
400 – 800	4
800 – 1200	3
1200 – 1600	2
1600 – 2000	1

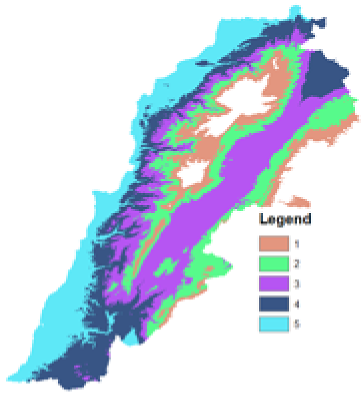


Figure 94. Reclassified table and map

f. <u>Criterion 6: Land Use and Land Cover</u>

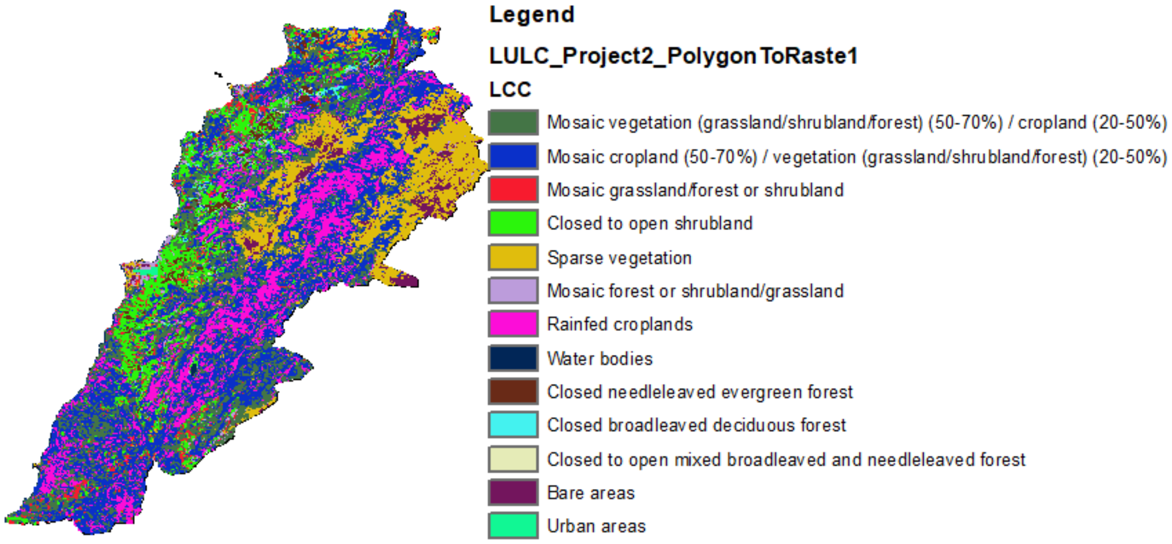


Figure 95. Land use and land cover map

The land use and land cover map was reclassified according to the following:

Old Values	New Values
Bare areas	1
Shrub land	2
Mosaic cropland	3
Vegetation	4
Forest	5

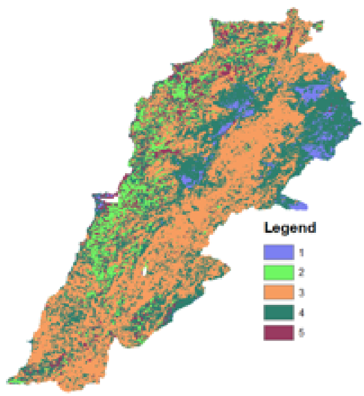


Figure 96. Reclassified table and map

g. <u>Criterion 7: Water Availability</u>

The minimum distance from water is 100 m and the maximum is 10 km. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 100m to 10km.

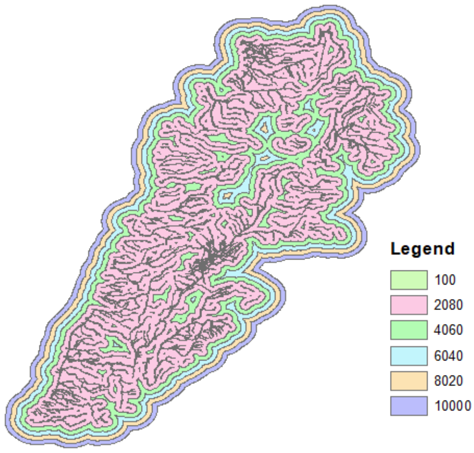


Figure 97. Multiple buffer zones for water availability map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near roads are considered the most important.

Old Values	New Values
0 – 100	NoData
1000 – 2080	5
2080 – 4060	4
4060 – 6040	3
6040 – 8020	2
8020 – 10000	1

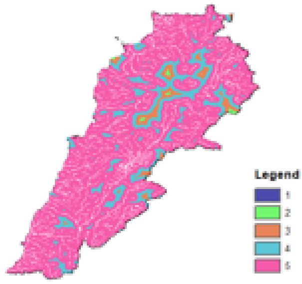


Figure 98. Reclassified table and map

4. Optimal Site Selection for Biomass Energy Sites

After arranging the criteria maps, it is time to combine everything together to obtain the final map, specifically the suitable site to install biomass power plants. For that, we will use the Map Algebra tool in GIS. We will sum the scores from all the layers and each score/criterion is multiplied by its weight (obtained from the multi-criteria decision making method, the AHP).

Here is the result:

Overall map=

"Biomass\criterion 1: proximity to road\Reclassification"*0.29+"Biomass\criterion 2: proximity to transmission line\Reclassification"*0.23+"Biomass\Criterion 3: population density"*0.16+"Biomass\criterion 4: slope\Reclassification"*0.023+"Biomass\Criterion 5: elevation\Reclassification"*0.16+
"Biomass\Criterion 6: land use and land cover\Reclassification"*0.29+"Biomass\criterion 7: water availability\Reclassification"*0.039

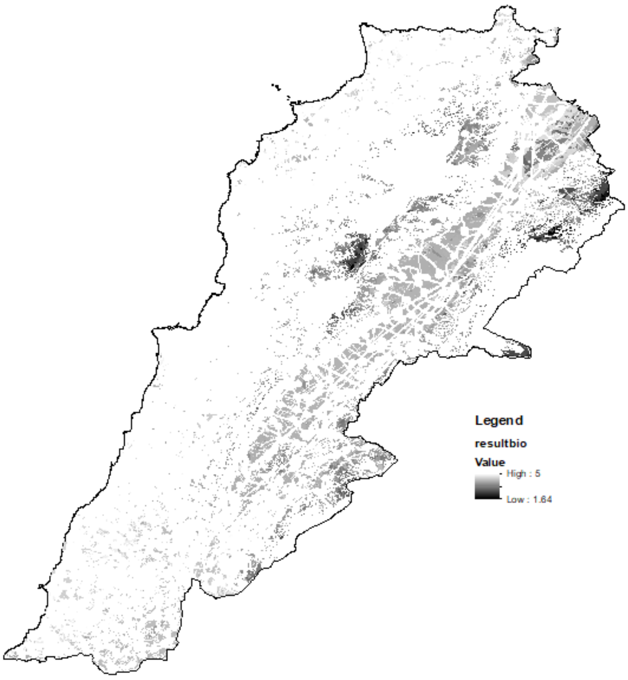


Figure 99. Optimal site location for biomass technology in Lebanon

F. GIS Analysis for Technology 6: Geothermal Energy

1. An Overview of Selected Criteria, Ranges and Weights

Table 48. Selected criteria, ranges and weights for the geothermal technology

ID	Criteria	Range (median from questionnaire)	Weight (%)
C1	Proximity to roads (in m)	Within 100m	26.74
C2	Distance to rural communities	>200m	6.37
C3	Land use and land cover	100m around well and hot springs (from the literature review)	66.89

2. An Overview of the Methodology

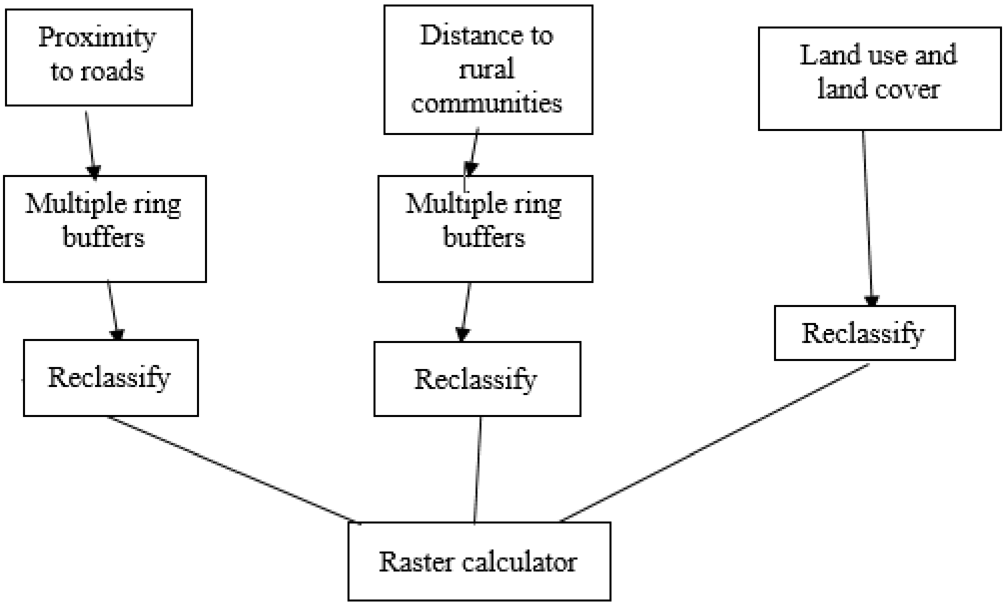


Figure 100. Methodology applied for technology 6: geothermal energy

3. Maps and Ranges

The following factors were considered in the site selection for geothermal power plant: proximity to roads, distance to rural communities, and land use land cover. Maps for each criterion were created based on a set of range.

a. <u>Criterion 1: Proximity to Roads</u>

The minimum distance from roads is 100 m and the maximum is 10 km. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 100m to 10km.

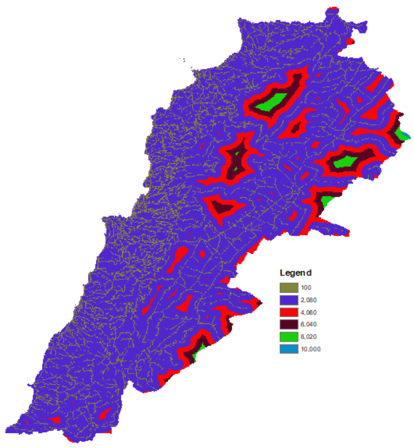


Figure 101. Multiple buffer zones for road map

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near roads are considered the most important.

Old Values	New Values
0 – 100	NoData
100 – 2080	5
2080 – 4060	4
4060 – 6040	3
6040 – 8020	2
8020 – 10000	1

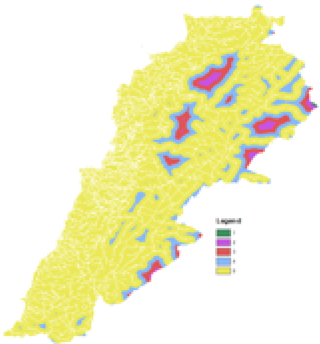


Figure 102. Reclassified table and map

b. Criterion 2: Distance to Rural Communities

The minimum distance from rural areas is 200 m and the maximum is 12000 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 200 m to 12 km.

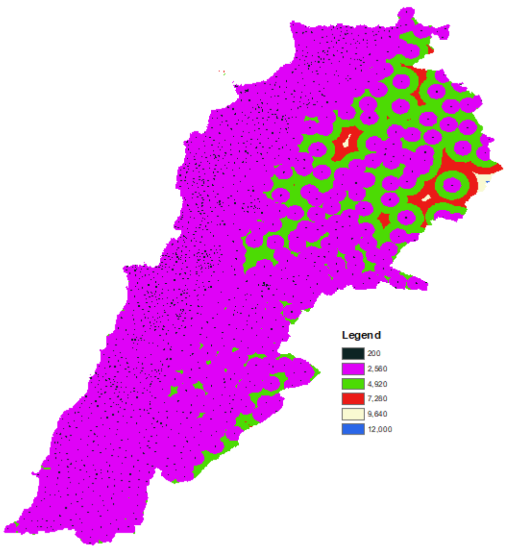


Figure 103. Multiple buffer zones for rural areas

Then, these buffer zones were classified into 5 categories where 5 is the most important value, areas near cities are considered the most important.

Old Values	New Values
0 – 200	NoData
200 – 2560	5
2560 – 4920	4
4920 – 7280	3
7280 – 9640	2
9640 – 12000	1

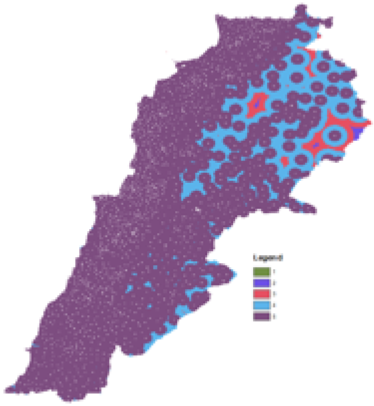


Figure 104. Reclassification table and map

c. <u>Criterion 3: Land Use and Land Cover</u>

A digitezed map of groundwater wells and springs were created from The National Geothermal Resource Assessment of Lebanon done by CEDRO.

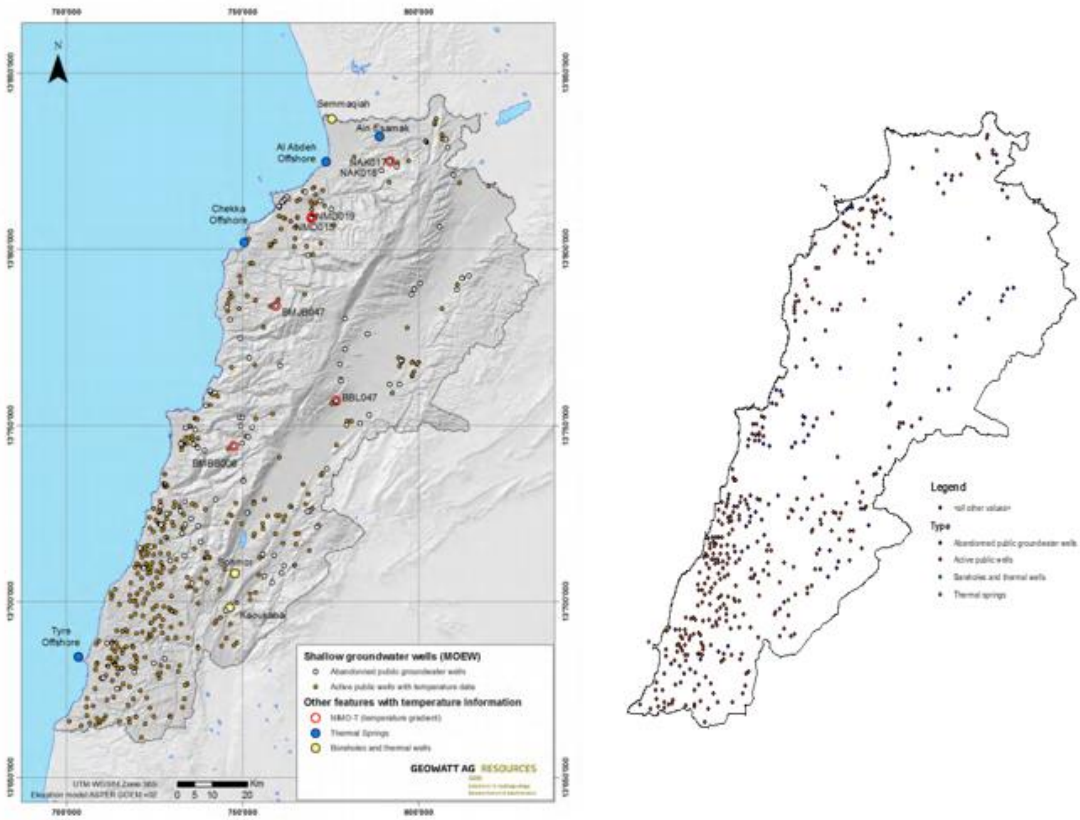


Figure 105. Groundwater wells and springs map

The minimum distance from wells and springs is 100 m and the maximum is 18000 m. Using multiple ring buffer tool in GIS, 5 buffer zones were created, ranging from a distance of 100 m to 18 km.

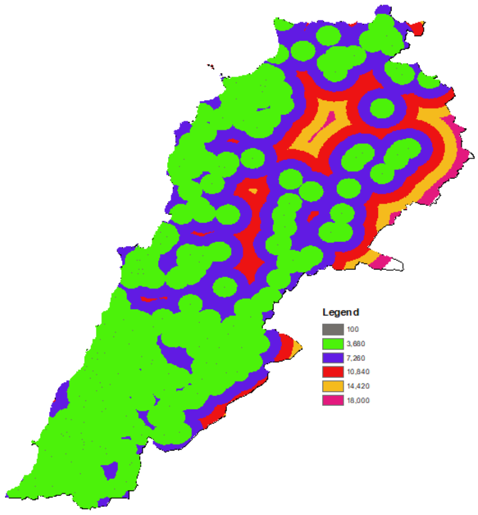


Figure 106. Multiple ring buffer map for wells and springs

Old Values	New Values
0 – 100	NoData
100 – 3680	5
3680 – 7260	4
7260 – 10840	3
10840 – 14420	2
14420 – 18000	1

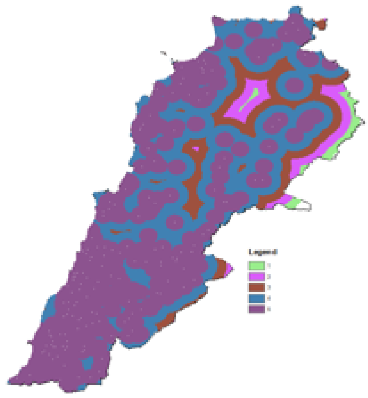


Figure 107. Reclassified table and map

4. Optimal Site Selection for Geothermal Energy Sites

After arranging the criteria maps, it is time to combine everything together to obtain the final map, specifically the suitable site to install geothermal power plants. For that, we will use the Map Algebra tool in GIS. We will sum the scores from all the layers and each score/criterion is multiplied by its weight (obtained from the multi-criteria decision making method, the AHP).

Here is the result:

Overall map= "Geothermal\Criterion 3: land use and land cover\Reclass"*0.67+"Geothermal\Criterion 2: distance to rural communities\Reclass"*0.06+"Geothermal\Criterion 1: proximity to road\Reclass"*0.27

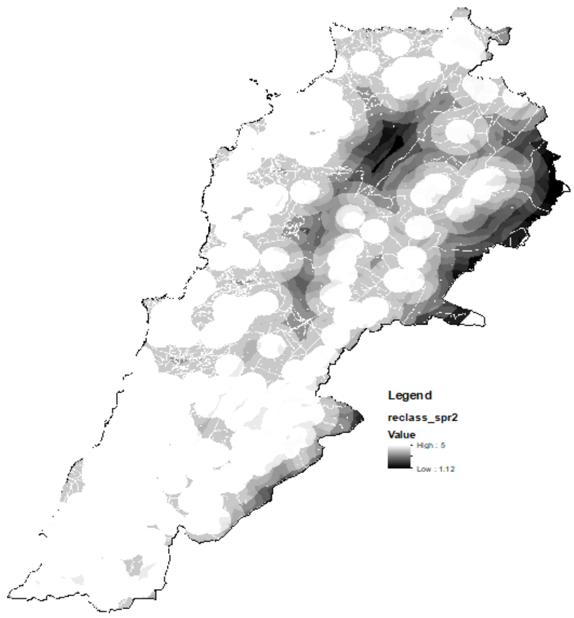


Figure 108. Optimal site location for geothermal technology in Lebanon

Discussion and Conclusion

By using spatial analysis function in GIS technology, based on weight calculation by using AHP model, a resources map was generated for prioritizing the decision for renewable energy development in the suitable site.

However, some of the energy map generated for the renewable energy technologies should be modified due to the fact that some criteria selected can be removed and the technology can be adjusted to adapt the new environment. These adjustment are related to the following technologies:

-The onshore wind technology: criteria like proximity to roads, distance to shore, distance to urban areas, and proximity to rural areas, are limiting the possibility of installing a wind farm where wind power density is considered high, and can be removed.

-The offshore wind technology: selecting criteria like slope and land cover and land use are not logically applicable for the offshore wind technology and can be removed.

-The PV technology: in this technology, installing PV rooftop should be taken into consideration. So, criteria like proximity to road, proximity to urban areas, distance to rural communities and land use and land cover, restrict the installation of this brand of technology and can be removed.

So, in the next chapter, the resources map will follow the adjustment for the energy map of the onshore, offshore and PV technologies and new results will be revealed.

CHAPTER VII

RESULTS BASED ON EXPERT FEEDBACK ENHANCED BY COMMON KNOWLEDGE

A. GIS Adjustment for Technology 1: Onshore Wind Energy

1. The Adjustment of Selected Criteria and Weights

Table 49. Selected criteria and weights for the onshore wind energy technology

ID	Criteria	Weight (%)	New Weight (%)
C1	Wind power density	37.17	63
C2	Proximity to transmission lines (in m)	12.50	21
C3	Slope	3.74	6.5
C8	Elevation	3.74	6.5
C9	Land use and land cover	1.61	3

The new weight is calculated by dividing the old weight over the sum of the old weights of the new selected criteria. The sum of the old weights is 58.76.

2. An Overview of the Methodology

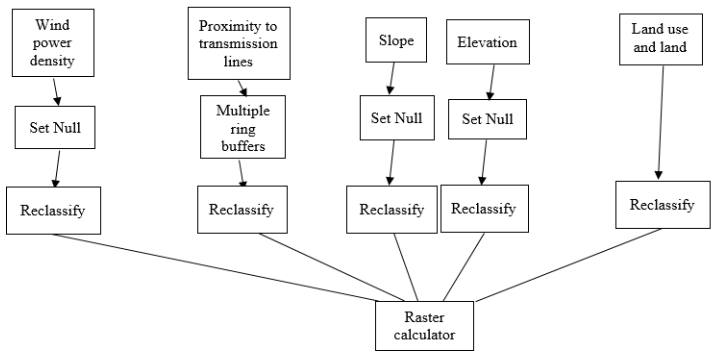


Figure 109. Methodology applied for technology 1: onshore energy

3. Maps and Ranges

Same process were adopt in this session by removing the following criteria: proximity to roads, distance to shore, distance to urban areas, and proximity to rural areas. These criteria limit the possibility of installing a wind farm where wind power density is high

4. Optimal Site Selection Adjustment for Onshore Wind Energy Sites

After arranging the criteria maps, the suitable site to install onshore wind farms were obtained by combining these criteria maps with corresponding new weights. Here is the result:

Overall map=
"Onshore wind\Criterion 1: wind power density\Reclassified"*0.63+"Onshore wind\Criterion 2: proximity to transmission lines\Reclassified"*0.21+"Onshore wind\Criterion 3: slope\Reclassified"*0.065+"Onshore wind\Criterion 4: elevation\Reclassified"*0.065+"Onshore wind\Criterion 5: land use and land cover\Reclassified"*0.03

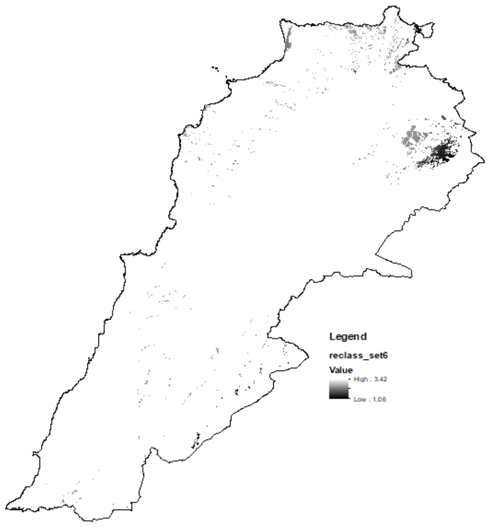


Figure 110. Optimal site location for onshore wind in Lebanon

B. GIS Adjustment for Technology 2: Offshore Wind Energy

1. The Adjustment of Selected Criteria and Weights

Table 50. Selected criteria and weights for the offshore wind energy technology

ID	Criteria	Weight (%)	New weight (%)
C1	Wind power density	72.35	100

2. An Overview of the Methodology

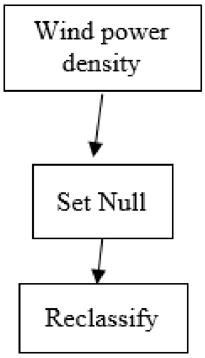


Figure 111. Methodology applied for technology 2: offshore wind energy

3. Maps and Ranges

The only criterion considered in site selection for offshore wind farm was wind power density. Criteria like slope and land use and land cover were eliminated. These criteria were considered irrelevant view the result obtained in the previous chapter. For this technology, slope and land use and land cover criteria showed up to be inappropriate factors.

4. Optimal Site Selection for Offshore Wind Energy Sites

In this case, the only criteria map selected is the wind power density criteria map. So the final map of the suitable site to install offshore wind farms include only the wind power density criteria.

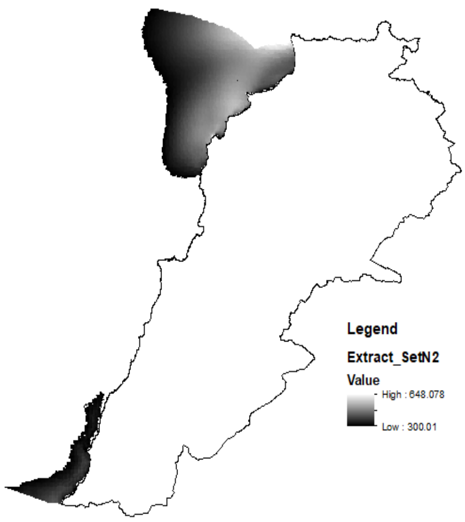


Figure 112. Optimal site location adjustment for offshore wind in Lebanon

C. GIS Analysis for Technology 3: PV Energy

1. The Adjustment of Selected Criteria and Weights

Table 51. Selected criteria and weights for the PV technology

ID	Criteria	Weight (%)	New weight (%)
C1	Solar irradiance	14.47	19
C3	Proximity to transmission lines (in m)	14.47	19
C4	Distance to shore	3.84	5
C7	Slope	14.47	19
C8	Elevation	14.47	19
C9	Aspect	14.47	19

The new weight is calculated by dividing the old weight over the sum of the old weights of the new selected criteria. The sum of the old weights is 76.19.

2. An Overview of the Methodology

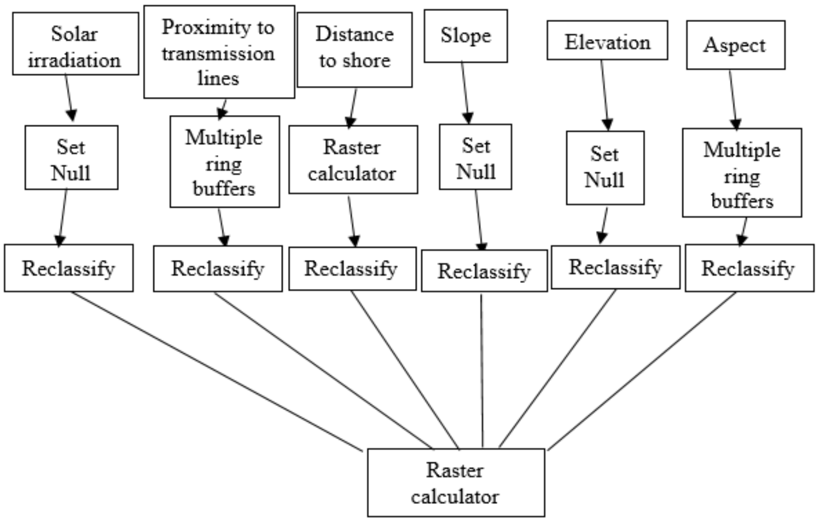


Figure 113. Methodology applied for technology 3: PV energy

3. Maps and Ranges

Same process were adopt in this session by removing the following criteria: proximity to roads, distance to urban areas, proximity to rural areas, and land use and land cover. These criteria limit the possibility of installing PV rooftop.

4. Optimal Site Selection for PV Energy Sites

After arranging the criteria maps, it is time to combine everything together to obtain the final map, specifically the suitable site to install PV farms. For that, we will use the Map Algebra tool in GIS. We will sum the scores from all the layers and each score/criterion is multiplied by its new weight.

Here is the result:

Overall map=

"PV\criterion 1: GHI\Reclassification"*0.19+"PV\criterion 2: proximity to transmission line\Reclassification"*0.19+"PV\Criterion 3: distance to shore\shoreline"*0.05+"PV\criterion 4: slope\Reclassification"*0.19+"PV\Criterion 5: elevation\Reclassification"*0.19+"PV\criterion 6: aspect\Reclassification"*0.19

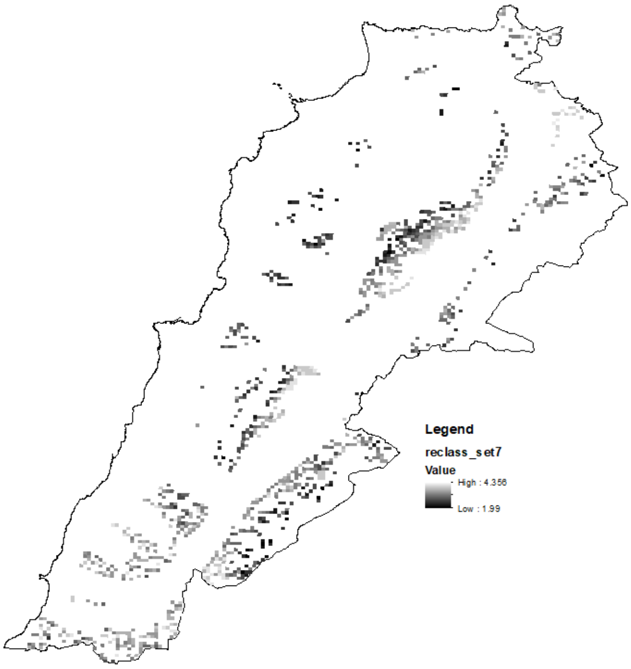


Figure 114. Optimal site location adjustment for PV technology in Lebanon

The next chapter discusses select an area and generates different scenarios for installing the possible renewable energy technology in this selected site.

CHAPTER VIII

EXAMPLE IMPLEMENTATION OF THE PROPOSED METHODOLOGY

After generating a representative map of Lebanon for the optimal site location for combined renewable energy installations, it is crucial to highlight some examples. In this chapter, we will elaborate on 2 examples: the first one addresses the selected area where most of the renewable energy technologies are available, and the second one represents a particular Lebanese town, Bint Jbeil.

For each renewable energy technology, color gradient was assigned for appropriate visualization:

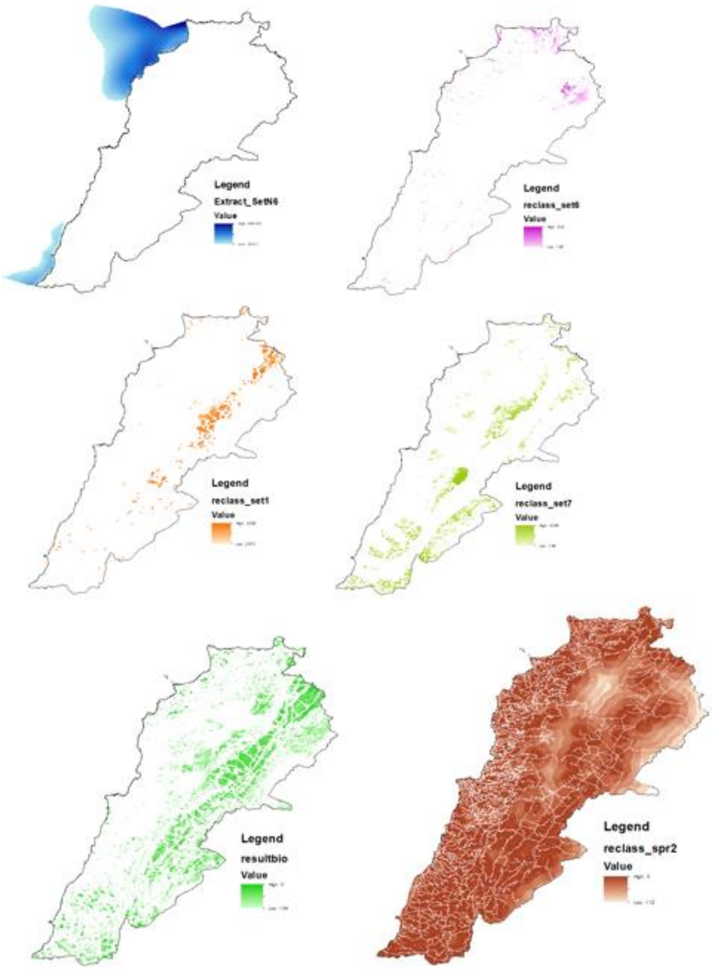


Figure 115. Energy maps: offshore wind map in blue, onshore wind map in purple, CSP map in orange, PV map in yellow, biomass map in green, and geothermal map in brown

The following table presents a reference table of the average power density and the average capital investment cost for the different renewable energy technologies.

Table 52. Average power density and the average capital investment cost table for renewable energy technologies [21, 22, 23, 24, 25]

	Onshore wind	Offshore wind	CSP	PV	Geothermal	Biomass
Average power density (W/m^2)	1	3	10	9	20	0.45
Average capital investment cost ($/kW)	1500	4353	5200	1210	3976	2100

A. Example A: Selected Area

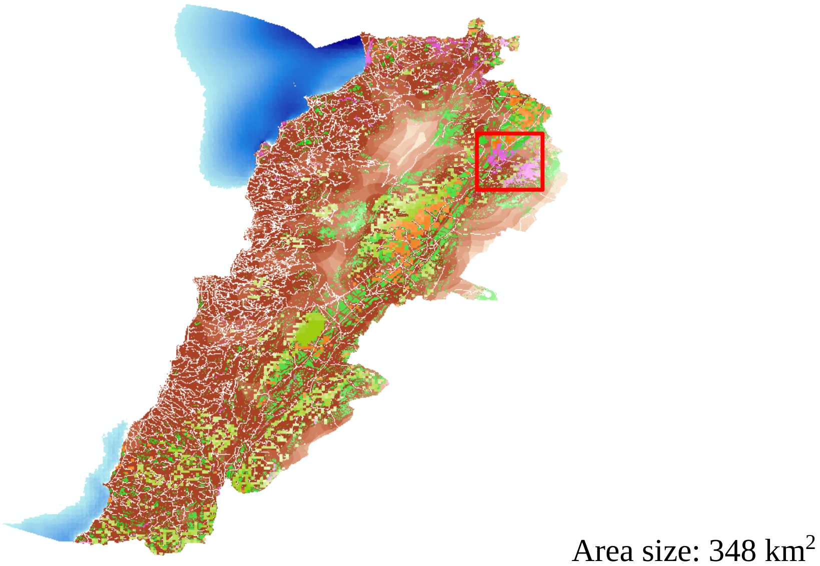


Figure 116. The selected area

For each renewable energy technology, the area to install the appropriate technology is calculated.

1. Onshore Wind Technology-Selected Area Calculation

First, we had to reclassify the area to convert it from raster to polygon.

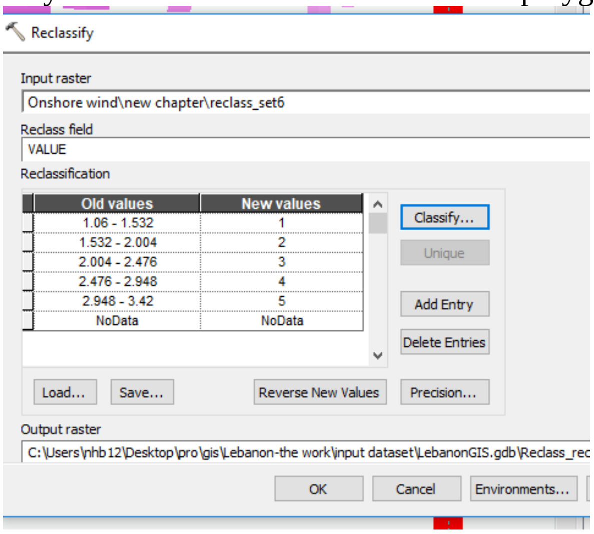


Figure 117. Reclassification table

Second, after converting the raster to polygon, we clipped the output polygon within the selected area to obtain the following map:

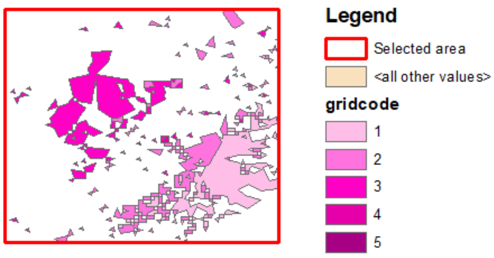


Figure 118. Reclassified map

Table 53. Classified areas for onshore wind technology

Classification		Onshore wind area (m^2)
From algebra map	Reclassification	
1.06 – 1.532	1	25 465 678
1.532 – 2.004	2	19 747 919
2.004 - 2.476	3	26 151 811
2.476 – 2.948	4	342 798
2.948 – 3.42	5	46 475

From the reference table [21], we collect the average power density for onshore wind energy: 1 W/m^2. We can say that by applying this technology, an energy ranges from 0-1 W can be produced on 1 m^2 area. Thus, we reclassify this power density scale into 5 classes as follows:

Table 54. Reclassified table of the power density

Reclassification scale	Power density scale (W/m^2)
1	0.2
2	0.4
3	0.6
4	0.8
5	1

To calculate the power for each area, we multiply the power density scale by the classified area of the applied technology.

Table 55. Power calculation for the onshore wind technology

Reclassification	Power density scale (W/m^2)	Onshore wind area (m^2)	Power density (W)	Power density (kW)
1	0.2	25 465 678	5 093 135	5 093
2	0.4	19 747 919	7 899 167	7 899
3	0.6	26 151 811	15 691 086	15 691
4	0.8	342 798	274 238	274
5	1	46 475	46 475	46
Total:		71 754 683	29 004 104	29 004

At this stage, we calculate the cost of installing the particular technology as follows:
The total cost to install onshore wind technology in the selected area is:
Power density (kw) X Average capital investment cost ($/kW)= $43 506 156.6

2. PV Technology-Selected Area Calculation

First, we had to reclassify the area to convert it from raster to polygon.

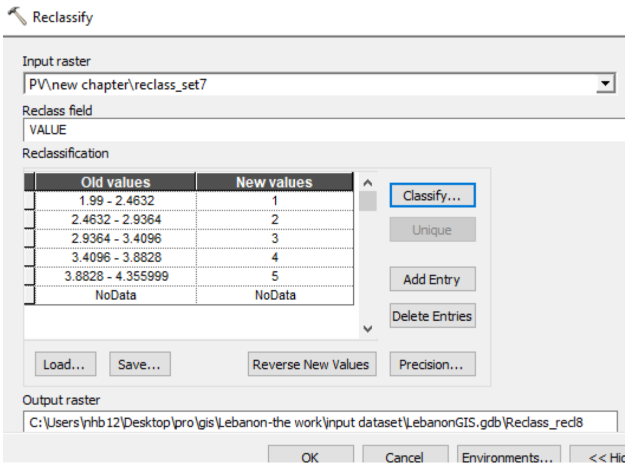


Figure 119. Reclassification table

Second, after converting the raster to polygon, we clipped the output polygon within the selected area to obtain the following map:

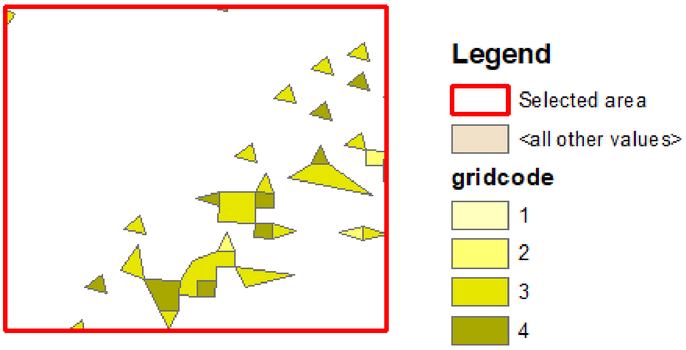


Figure 120. Reclassified map

Table 56. Classified areas for PV technology

Classification		PV area (m²)
From algebra map	Reclassification	
1.99 – 2.4632	1	17 186
2.4632 – 2.9364	2	1 744 729
2.9364 - 3.4096	3	17 973 627
3.4096 – 3.8828	4	7 300 852
3.8828 – 4.355999	5	0

From the reference table [22], we collect the average power density for PV energy: 9 W/m^2. We can say that by applying this technology, an energy ranges from 0-9 W can be produced on 1 m^2 area. Thus, we reclassify this power density scale into 5 classes as follows:

Table 57. Reclassified table of the power density

Reclassification scale	Power density scale (W/m^2)
1	1.8
2	3.6
3	5.4
4	7.2
5	9

To calculate the power for each area, we multiply the power density scale by the classified area of the applied technology.

Table 58. Power calculation for the PV technology

Reclassification	Power density scale (W/m^2)	PV area (m^2)	Power density (W)	Power density (kW)
1	1.8	17 186	30 935	30
2	3.6	1 744 729	6 281 024	6 281
3	5.4	17 973 627	97 057 586	97 057
4	7.2	7 300 852	52 566 137	52 566
5	9	0	0	0
Total:		27 036 395	155 935 684	155 935

At this stage, we calculate the cost of installing the particular technology as follows:
The total cost to install PV technology in the selected area is:
Power density (kw) X Average capital investment cost ($/kW)= $188 682 177.6

3. CSP Technology-Selected Area Calculation

First, we had to reclassify the area to convert it from raster to polygon.

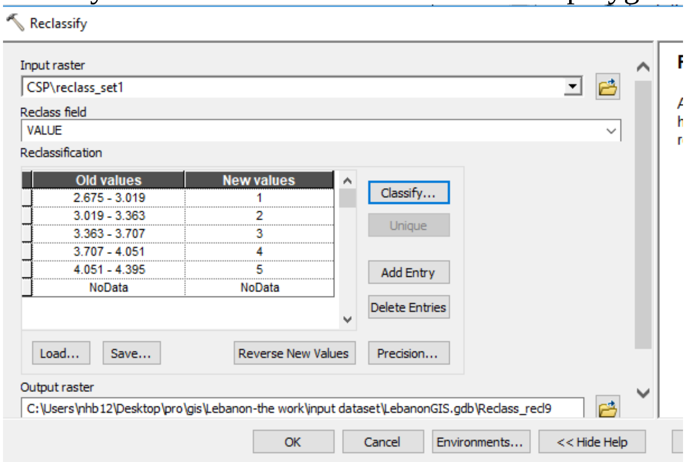


Figure 121. Reclassification table

Second, after converting the raster to polygon, we clipped the output polygon within the selected area to obtain the following map:

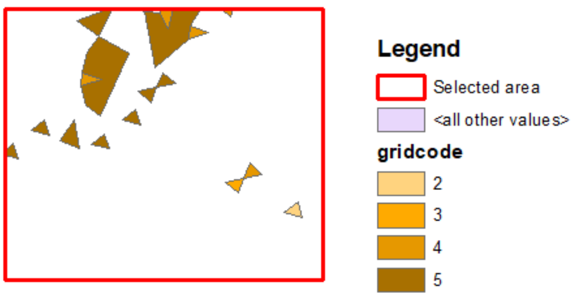


Figure 122. Reclassified map

Table 59. Classified areas for CSP technology

Classification		CSP area (m^2)
From algebra map	Reclassification	
2.675 – 3.019	1	0
3.019 – 3.363	2	523 743
3.363 - 3.707	3	523 743
3.707 – 4.051	4	2 298 473
4.051 – 4.395	5	21 383 205

From the reference table [22], we collect the average power density for CSP energy: 10 W/m^2. We can say that by applying this technology, an energy ranges from 0-10 W can be produced on 1 m^2 area. Thus, we reclassify this power density scale into 5 classes as follows:

Table 60. Reclassified table of the power density

Reclassification scale	Power density scale (W/m^2)
1	2
2	4
3	6
4	8
5	10

To calculate the power for each area, we multiply the power density scale by the classified area of the applied technology.

Table 61. Power calculation for the CSP technology

Reclassification	Power density scale (W/m^2)	CSP area (m^2)	Power density (W)	Power density (kW)
1	2	0	0	0
2	4	523 743	2 094 972	2 094
3	6	523 743	3 142 458	3 142
4	8	2 298 473	18 387 785	18 387
5	10	21 383 205	213 832 055	213 832
Total:		24 729 164	237 457 271	237 457

At this stage, we calculate the cost of installing the particular technology as follows:
The total cost to install CSP technology in the selected area is:
Power density (kw) X Average capital investment cost ($/kW)= $1 234 777 492

4. Geothermal Technology-Selected Area Calculation

First, we had to reclassify the area to convert it from raster to polygon.

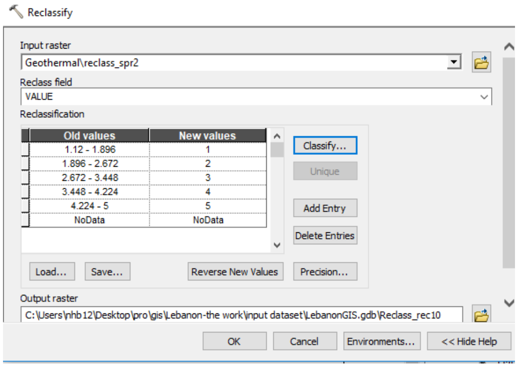


Figure 123. Reclassification table

Second, after converting the raster to polygon, we clipped the output polygon within the selected area to obtain the following map:

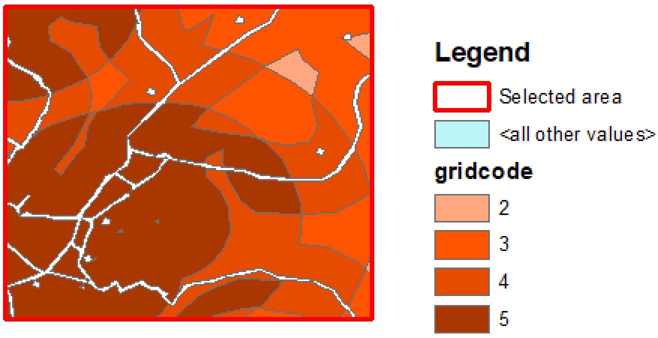


Figure 124. Reclassified map

Table 62. Classified areas for geothermal technology

Classification		Geothermal area (m^2)
From algebra map	Reclassification	
1.12 – 1.896	1	0
1.896 – 2.672	2	5 027 385
2.672 - 3.448	3	68 832 084
3.448 – 4.224	4	98 313 169
4.224 – 5	5	154 987 377

From the reference table [23], we collect the average power density for geothermal energy: 20 W/m^2. We can say that by applying this technology, an energy ranges from 0-20 W can be produced on 1 m^2 area. Thus, we reclassify this power density scale into 5 classes as follows:

Table 63. Reclassified table of the power density

Reclassification scale	Power density scale (W/m^2)
1	4
2	8
3	12
4	16
5	20

To calculate the power for each area, we multiply the power density scale by the classified area of the applied technology.

Table 64**.** Power calculation for the geothermal technology

Reclassification	Power density scale (W/m^2)	Geothermal area (m^2)	Power density (W)	Power density (kW)
1	4	0	0	0
2	8	5 027 385	40 219 082	40 219
3	12	68 832 084	825 985 014	825 985
4	16	98 313 169	1 573 010 720	1 573 010
5	20	154 987 377	3 099 747 546	3 099 747
Total:		327 160 017	5 538 962 362	5 538 962

At this stage, we calculate the cost of installing the particular technology as follows:
The total cost to install geothermal power plant in the selected area is:
Power density (kw) X Average capital investment cost (\$/kW)= \$2.2 x 10^{10}
While numbers appear to be too high, more specific criteria can provide more realistic energy estimates for this kind of technology.

5. Biomass Technology-Selected Area Calculation

First, we had to reclassify the area to convert it from raster to polygon.

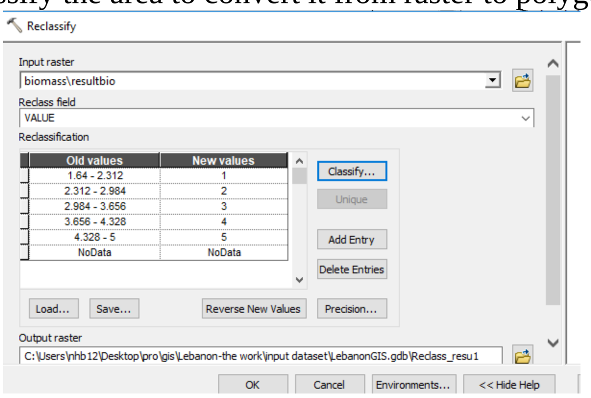


Figure 125. Reclassification table

Second, after converting the raster to polygon, we clipped the output polygon within the selected area to obtain the following map:

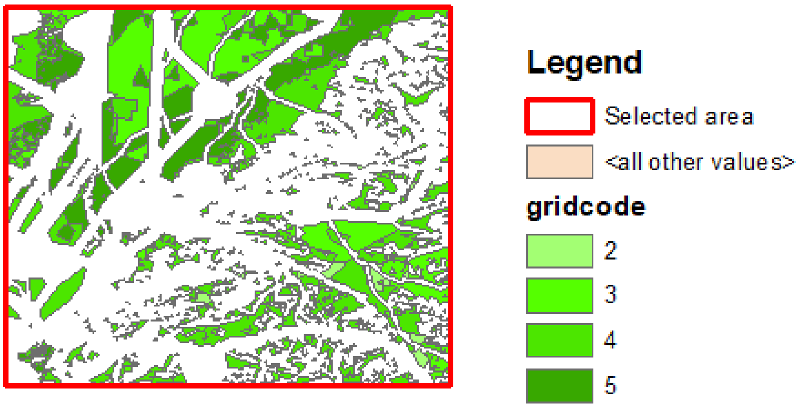


Figure 126. Reclassified map

Table 65. Classified areas for biomass technology

Classification		Biomass area (m^2)
From algebra map	Reclassification	
1.64 – 2.312	1	0
2.312 – 2.984	2	2 734 407
2.984 - 3.656	3	32 794 349
3.656 – 4.328	4	57 602 430
4.328 – 5	5	30 120 071

From the reference table [24], we collect the average power density for biomass energy: 0.45 W/m^2. We can say that by applying this technology, an energy ranges from 0-0.45 W can be produced on 1 m^2 area. Thus, we reclassify this power density scale into 5 classes as follows:

Table 66. Reclassified table of the power density

Reclassification scale	Power density scale (W/m^2)
1	0.09
2	0.18
3	0.27
4	0.36
5	0.45

To calculate the power for each area, we multiply the power density scale by the classified area of the applied technology.

Table 67. Power calculation for the biomass technology

Reclassification	Power density scale (W/m^2)	Biomass area (m^2)	Power density (W)	Power density (kW)
1	0.09	0	0	0
2	0.18	2 734 407	492 193	492
3	0.27	32 794 349	88 544 74	8 854
4	0.36	57 602 430	20 736 875	20 736
5	0.45	30 120 071	13 554 032	13 554
Total:		123 251 259	43 637 574	43 637

At this stage, we calculate the cost of installing the particular technology as follows:
The total cost to install a biomass power plant in the selected area is:
Power density (kw) X Average capital investment cost ($/kW)= $91 638 907.29
While numbers appear to be too high, more specific criteria can provide more realistic energy estimates for this kind of technology.

Summary

Table 68. Summary table of example A

	Onshore wind	Offshore wind	CSP	PV	Geothermal	Biomass
Average power density (W/m^2)	1	3	10	9	20	0.45
Average capital investment cost ($/kW)	1500	4 353	5 200	1 210	3 976	2 100
Total investment ($)	43 506 156	Not available	1 234 777 492	188 682 177	2.2×10^{10}	91 638 907
Power production (kW)	29 004	Not available	237 457	155 935	5 538 962	43 637

A. Example B: Bint Jbeil

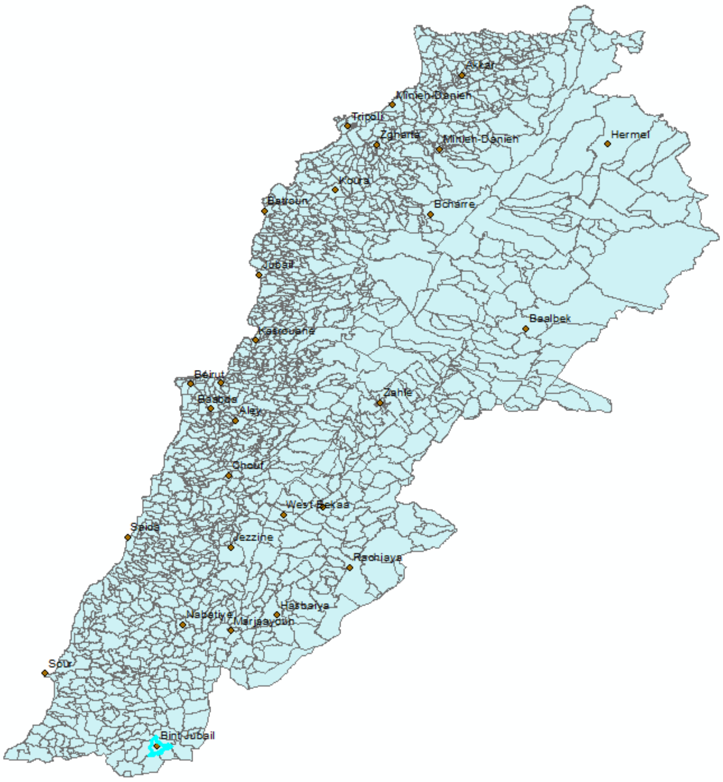


Figure 127. Cadaa map of Lebanon

cadast_limits_Project

OBJECTID *	Shape *	AREA	PERIMETER	CADAST_LIM	CADAST_L_1	ACS_CODE	CAD_CODE	ACS_NAME	CAD_NAME	ADMIN_CAZA	CAD_CAZA	ACS_CD_SP	UN_ID	KADA_NA	MOH_NA1	POP_AREA	POP_SUR1	LOG_SUT	LOG_SUR	Shape_Length	Shape_A
1583	Polygon	1153900	4937.790039	1584	1841	62267	62015	Kneisset Sour	Kneissé	21	21	62267	1551	Sour	South	5.5	0	1.2	0	4938.832037	1154387.
1584	Polygon	3043170	7655.049805	1585	1842	62259	62017	Rmadiyé	Remadiyeh	21	21	62259	1552	Sour	South	4.7	35.17	1.17	9	7656.702694	3044495.
1585	Polygon	2110060	7547.180176	1586	1843	62226	62055	Biyad	El-Biyad	21	21	62226	1553	Sour	South	4.6	72.95	1.09	17	7548.951408	2111087.
1586	Polygon	1641000	6525.069824	1587	1844	62223	62056	Deir Aames	Deir Amess	21	21	62223	1554	Sour	South	7.1	59.53	1.75	15	6526.759006	1641810.
1587	Polygon	6148650	11363	1588	1845	62236	62057	Recheknanay	Recheknaniyeh	21	21	62236	1555	Sour	South	1.2	67.59	0.27	16	11365.713423	6151568.
1588	Polygon	7900830	14888.400391	1589	1846	72211	72001	Tibnine	Tibnine	24	24	72211	1556	Bint Jubail	Nabatiye	3.6	24.86	1.39	9	14892.468671	7905230.
1589	Polygon	1689740	6411.580078	1590	1847	72217	72010	Safad Al-Battikh	Safad-el-Battikh	24	24	72217	1557	Bint Jubail	Nabatiye	3.3	60.17	0.75	14	6413.430617	1690741.
1590	Polygon	16873800	19989.099609	1591	1848	72229	72050ND	Chaqra	Chakra	24	24	72229	1558	Bint Jubail	Nabatiye	2.4	44.59	0.72	13	19995.327466	16884088.
1591	Polygon	10677200	21607.599609	1592	1849	72257	72015	Kafra Bant Jbayl	Kafra	24	24	72257	1559	Bint Jubail	Nabatiye	1.4	25.32	0.58	11	21612.6685	10682330.
1592	Polygon	2195080	7008.259766	1593	1850	62241	62058	Sadiqine	Saddikine	21	21	62241	1560	Sour	South	9.8	42.51	2.04	9	7009.796433	2196081.
1593	Polygon	19221100	20786.800781	1594	1851	73250	73029ND	Meiss Ej-Jabal	Meis El-Jabal	25	25	73250	1561	Marjaayoun	Nabatiye	1.6	67.87	0.67	28	20793.625027	19233693.
1594	Polygon	1644060	7420.189941	1595	1852	62293	62011	Henniyé	El-Henniyé	21	21	62293	1562	Sour	South	4.7	48.82	1.12	12	7421.479426	164466
1595	Polygon	14463300	19595.099609	1596	1853	62279	62059	Jbal El-Botm	Jebel-El-Batm	21	21	62279	1563	Sour	South	0.8	71.72	0.21	19	19599.28981	14469413.
1596	Polygon	8002720	15917.900391	1597	1854	72241	72014	Haris	Harisse	24	24	72241	1564	Bint Jubail	Nabatiye	4.4	60.94	0.88	12	15921.94548	8006822.
1597	Polygon	6301850	12471.400391	1598	1855	72227	72011	Baraachit	Baraachite	24	24	72227	1565	Bint Jubail	Nabatiye	2.4	29.85	1.03	13	12475.14566	6305504.
1598	Polygon	7456090	14718.200195	1599	1856	62296	62013	Mansouri Sour	El-Mansouri	21	21	62296	1566	Sour	South	3.1	60.41	0.94	18	14720.568997	7458645.
1599	Polygon	7680190	16679.300781	1600	1857	62294	62012	Aaziyé	Izzié	21	21	62294	1567	Sour	South	0	3.42	0.01	1	16682.412454	768308
1600	Polygon	14559400	21726.300781	1601	1858	62286	62060	Zebqine	Zebkine	21	21	62286	1568	Sour	South	0.8	207.6	0.2	52	21730.712213	14565083.
1601	Polygon	1434630	5700.72998	1602	1859	62242	62064ND	Aalyé	Aalyé	21	21	62242	1569	Sour	South	4.1	31.08	0.84	6	5701.958881	1435273.
1602	Polygon	4982260	11717.299805	1603	1860	72224	72012	Aaita Ej-Jabal	Aïta-el-Zut	24	24	72224	1570	Bint Jubail	Nabatiye	1.8	24.46	0.48	6	11720.355735	4984980.
1603	Polygon	10850600	17818.300781	1604	1861	62297	62061	Majdelzoun	Majdalzoun	21	21	62297	1571	Sour	South	0.9	36.59	0.31	12	17821.383174	10854407.
1604	Polygon	8078320	12992.700195	1605	1862	62299	62063	Iskandarouna Sour	Eskandaroun	21	21	62299	1572	Sour	South	0	27.48	0	0	12994.654312	8080791.
1605	Polygon	6423730	12055.5	1606	1863	72231	72013	Haddatha	Haddacé	24	24	72231	1573	Bint Jubail	Nabatiye	3.3	43.58	0.63	8	12058.690024	6427019.
1606	Polygon	4850790	11226.599609	1607	1864	72237	72018	Beit Yahoun	Beit Yahoune	24	24	72237	1574	Bint Jubail	Nabatiye	0.5	6.26	0.11	1	11229.639041	4853439.
1607	Polygon	10026100	15241	1608	1865	72277	72016	Yater	Yater	24	24	72277	1575	Bint Jubail	Nabatiye	1.4	30.29	0.61	13	15244.311418	10030491.
1608	Polygon	12920800	18058.599609	1609	1866	72251	72022	Kounine	Kounine	24	24	72251	1576	Bint Jubail	Nabatiye	0.2	11.45	0.04	2	18063.596389	12928116.
1609	Polygon	3947350	10974	1610	1867	72267	72017	Srobbine	Sarbine	24	24	72267	1577	Bint Jubail	Nabatiye	0.2	9.38	0.17	10	10976.567962	3949241.
1610	Polygon	4133260	8875.849609	1611	1868	62298	62062	Chamaa	Chameh	21	21	62298	1578	Sour	South	0.5	26.87	0.2	10	8877.295083	4134569.
1611	Polygon	4750890	11017.299805	1612	1869	73248	73028ND	Mhaibib	Mhaibib	25	25	73248	1579	Marjaayoun	Nabatiye	1.4	60.22	0.34	14	11020.635577	4753844.
1612	Polygon	13287700	17449.5	1613	1870	73288	73035ND	Blida	Blida	25	25	73288	1580	Marjaayoun	Nabatiye	1.2	28.08	0.48	12	17454.889281	13295905.
1613	Polygon	7657600	13707.099609	1614	1871	62314	62070ND	Hamoul	Hamoul	21	21	62314	1581	Sour	South	0	0	0	0	13708.923765	7659697.
1614	Polygon	7617140	16814.900391	1615	1872	72254	72021	Tiri	El-Tairi	24	24	72254	1582	Bint Jubail	Nabatiye	0.5	22.67	0.41	20	16818.971149	762099
1615	Polygon	3487800	7539.140137	1616	1873	72271	72020	Rachaf	Rachafe	24	24	72271	1583	Bint Jubail	Nabatiye	0	0	0.11	1	7540.882212	3489446.
1616	Polygon	4466360	9914.599609	1617	1874	62295	62067ND	Tayr Harfa	Tair Harf	21	21	62295	1584	Sour	South	1.5	52.55	0.43	15	9916.276846	4467813.
1617	Polygon	4595070	12886.5	1618	1875	72287	72019	Beit Lif	Beit Lif	24	24	72287	1585	Bint Jubail	Nabatiye	4.5	110.58	0.94	23	12889.318162	4597055.
1618	Polygon	2993980	8880.490234	1619	1876	62292	62066ND	Jibbayn	El Jbine	21	21	62292	1586	Sour	South	1.3	36.86	0.28	8	8882.01011	2994979.
1619	Polygon	5482610	9842.360352	1620	1877	62285	62065ND	Chihine	Chihine	21	21	62285	1587	Sour	South	1	91.78	0.22	21	9844.016162	54845
1620	Polygon	3158410	7555.779785	1621	1878	62318	62072ND	Jijim	Jejime	21	21	62318	1588	Sour	South	0	0	0	0	7556.850144	3159314.
1621	Polygon	2515070	6984.310059	1622	1879	62319	62073ND	Abou Chech	Abou Chech	21	21	62319	1589	Sour	South	0.4	35.57	0.06	6	6985.374749	2515841.
1622	Polygon	8009380	16951	1623	1880	72111	72036	Bent Jbayl	Bint Jbail	24	24	72111	1590	Bint Jubail	Nabatiye	11.5	81.24	2.91	21	16955.442828	8013538.
1623	Polygon	1815280	5338.310059	1624	1881	72135	72024	Salhani	Salhané	24	24	72135	1591	Bint Jubail	Nabatiye	0	0	0.01	2	5339.380358	1816010.
1624	Polygon	8473420	17929.199219	1625	1882	72281	72027	Debl	Debel	24	24	72281	1592	Bint Jubail	Nabatiye	1.9	63.87	0.44	15	17933.286292	8477374.
1625	Polygon	4367750	10638.099609	1626	1883	72119	72023	Aaynata Bent Jbayl	Ainata	24	24	72119	1593	Bint Jubail	Nabatiye	8.1	43.14	1.46	8	10640.86196	4370141.
1626	Polygon	5406420	11442.200195	1627	1884	72291	72026	Qaouzah	El-Kouzah	24	24	72291	1594	Bint Jubail	Nabatiye	1.2	77.22	0.21	14	11444.646986	5408750.
1627	Polygon	10536200	19470.199219	1628	1885	62312	62069ND	Borj En-Naqoura	Nakoura	21	21	62312	1595	Sour	South	1.6	29.36	0.36	9	19472.268967	10538522.
1628	Polygon	11546000	16652.099609	1629	1886	72143	72030	Aain Ibl	Ain-Ebel	24	24	72143	1596	Bint Jubail	Nabatiye	2.2	33.11	0.51	8	16656.184092	11551501.
1629	Polygon	13606000	20031.199219	1630	1887	72151	72035	Aaintaroun	Aitaroun	24	24	72151	1597	Bint Jubail	Nabatiye	3.1	47.59	0.91	14	20036.763727	13613702.
1630	Polygon	19593100	27227.400391	1631	1888	62316	62071ND	Aalma Ech-Chaab	Alma Chaab	21	21	62316	1598	Sour	South	0.7	59.14	0.19	17	27230.561255	19597991.
1631	Polygon	9993690	15381.700195	1632	1889	62311	62078ND	Merouahine	Marouhine	21	21	62311	1599	Sour	South	1.7	59.64	0.3	12	15384.231243	9997317.
1632	Polygon	6117370	11485.599609	1633	1890	72191	72025	Ramyet Bent Jbayl	Ramé	24	24	72191	1600	Bint Jubail	Nabatiye	2	91.98	0.42	19	11487.84136	6119788.
1633	Polygon	2587400	8032.109863	1634	1891	62331	62075ND	Btaychiyé	Btaychiyé	21	21	62331	1601	Sour	South	0.2	0	0.03	0	8033.277009	2588143.
1634	Polygon	3717670	11505.299805	1635	1892	62341	62076ND	Dhayra	Mazraat Dhaira	21	21	62341	1602	Sour	South	1.9	30.01	0.38	7	11506.952953	3718795.
1635	Polygon	2102510	10146.5	1636	1893	62351	62077ND	Mazraat Ez-Zalloutiyeh	Mazraat Ez-Zalloutieh	21	21	62351	1603	Sour	South	0.4	6.92	0.06	1	10148.057788	2103212.
1636	Polygon	3277770	10385.5	1637	1894	62308	62068ND	Yarine	Yarine	21	21	62308	1604	Sour	South	4.2	73.1	0.81	14	10387.159624	3278797.
1637	Polygon	6171630	11037	1638	1895	72284	72029	Hanine	Hanine	24	24	72284	1605	Bint Jubail	Nabatiye	0	2.53	0.09	6	11039.606813	6174391.
1638	Polygon	7527190	14166.200195	1639	1896	72127	72034	Maroun Er-Ras	Maroune-el-Ras	24	24	72127	1606	Bint Jubail	Nabatiye	0.5	5.4	0.14	2	14169.847334	7531163.

Figure 128. Cadaa table of Lebanon

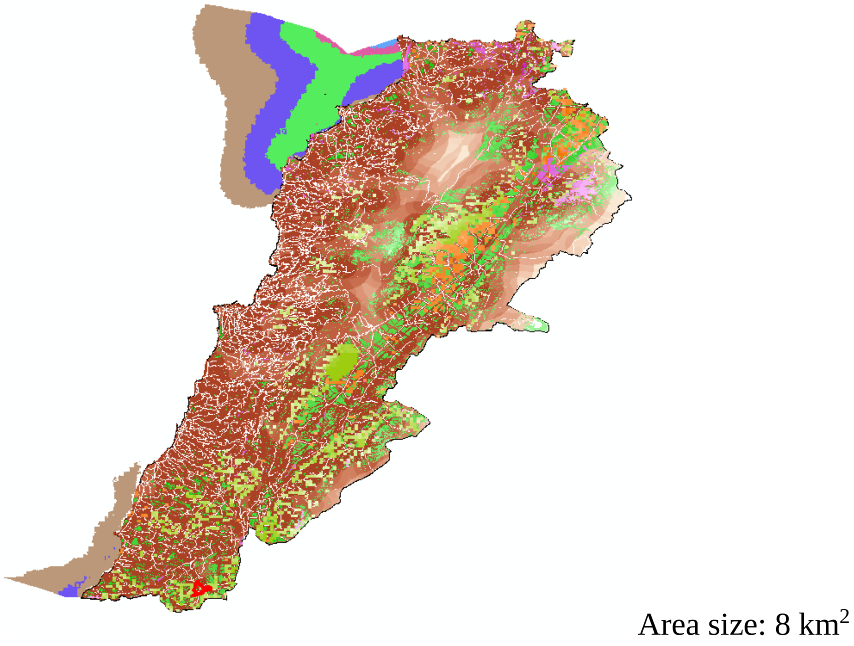


Figure 129. Overview map of Lebanon of the different renewable energy technologies and the selected area

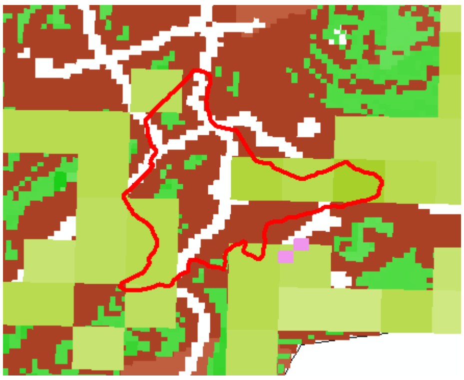


Figure 130.The selected area-Bint Jbeil

Only 3 technologies can be installed in Bint Jbeil: PV, biomass and geothermal.

For each renewable energy technology, the area to install the appropriate technology is calculated.

1. PV Technology-Selected Area Calculation

First, we had to reclassify the area to convert it from raster to polygon.

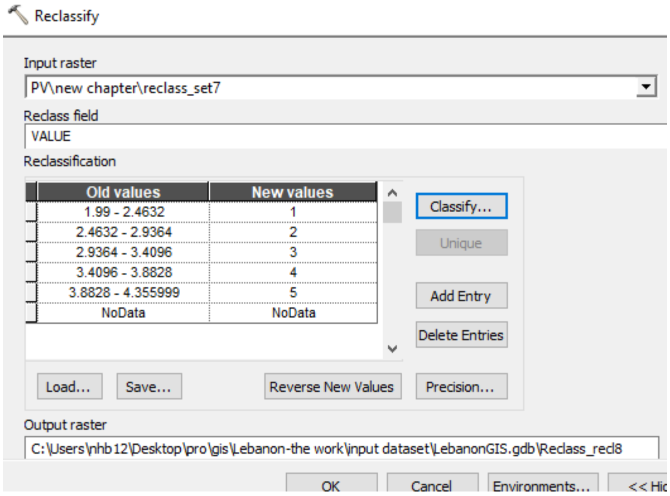


Figure 131. Reclassification table

Second, after converting the raster to polygon, we clipped the output polygon within the selected area to obtain the following map:

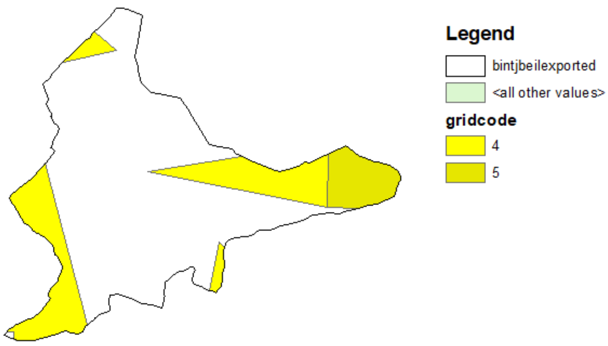


Figure 132. Reclassified map

Table 69. Classified areas for PV technology

Classification		PV area (m^2)
From algebra map	Reclassification	
1.99 – 2.4632	1	0
2.4632 – 2.9364	2	0
2.9364 - 3.4096	3	0
3.4096 – 3.8828	4	1 669 044
3.8828 – 4.355999	5	510 111

From the reference table [22], we collect the average power density for PV energy: 9 W/m^2. We can say that by applying this technology, an energy ranges from 0-9 W can be produced on 1 m^2 area. Thus, we reclassify this power density scale into 5 classes as follows:

Table 70. Reclassified table of the power density

Reclassification scale	Power density scale (W/m^2)
1	1.8
2	3.6
3	5.4
4	7.2
5	9

To calculate the power for each area, we multiply the power density scale by the classified area of the applied technology.

Table 71. Power calculation for the PV technology

Reclassification	Power density scale (W/m^2)	PV area (m^2)	Power density (W)	Power density (kW)
1	1.8	0	0	0
2	3.6	0	0	0
3	5.4	0	0	0
4	7.2	1 669 044	12 017 120	12 017
5	9	510 111	4 591 003	4 591
Total:		2 179 155	16 608 123	16 608

At this stage, we calculate the cost of installing the particular technology as follows:
The total cost to install PV technology in the selected area is:
Power density (kw) X Average capital investment cost ($/kW)= $20 095 829.68

2. Geothermal Technology-Selected Area Calculation

First, we had to reclassify the area to convert it from raster to polygon.

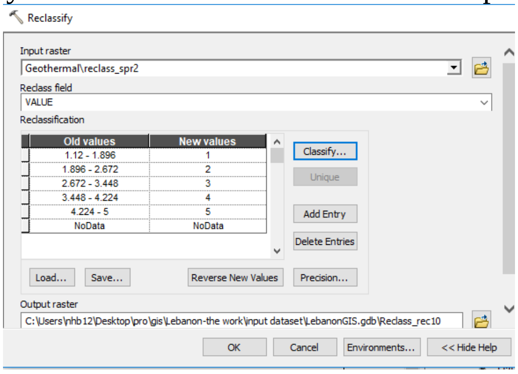


Figure 133. Reclassification table

Second, after converting the raster to polygon, we clipped the output polygon within the selected area to obtain the following map:

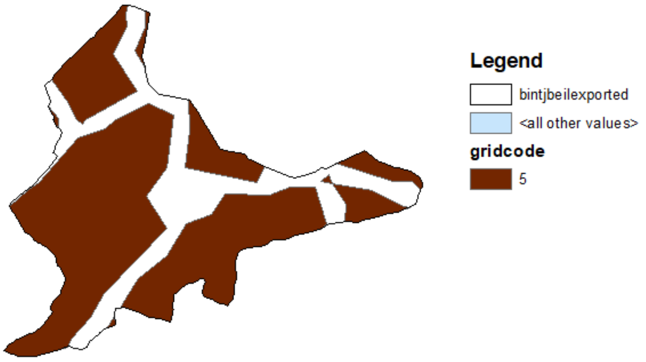


Figure 134. Reclassified map

Table 72. Classified areas for geothermal technology

Classification		Geothermal area (m^2)
From algebra map	Reclassification	
1.12 – 1.896	1	0
1.896 – 2.672	2	0
2.672 - 3.448	3	0
3.448 – 4.224	4	0
4.224 – 5	5	5 825 426

From the reference table [23], we collect the average power density for geothermal energy: 20 W/m^2. We can say that by applying this technology, an energy ranges from 0-20 W can be produced on 1 m^2 area. Thus, we reclassify this power density scale into 5 classes as follows:

Table 73. Reclassified table of the power density

Reclassification scale	Power density scale (W/m^2)
1	4
2	8
3	12
4	16
5	20

To calculate the power for each area, we multiply the power density scale by the classified area of the applied technology.

Table 74. Power calculation for the geothermal technology

Reclassification	Power density scale (W/m^2)	Geothermal area (m^2)	Power density (W)	Power density (kW)
1	4	0	0	0
2	8	0	0	0
3	12	0	0	0
4	16	0	0	0
5	20	5 825 426	116 508 539	116 508
Total:		5 825 426	116 508 539	116 508

At this stage, we calculate the cost of installing the particular technology as follows:
The total cost to install geothermal power plant in the selected area is:
Power density (kw) X Average capital investment cost ($/kW)= $463 237 951.1

5. Biomass Technology-Selected Area Calculation

First, we had to reclassify the area to convert it from raster to polygon.

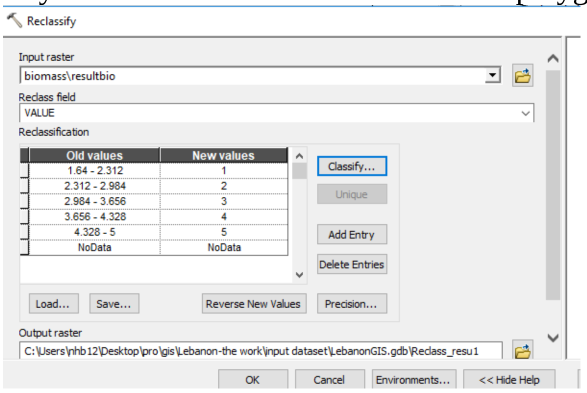


Figure 135. Reclassification table

Second, after converting the raster to polygon, we clipped the output polygon within the selected area to obtain the following map:

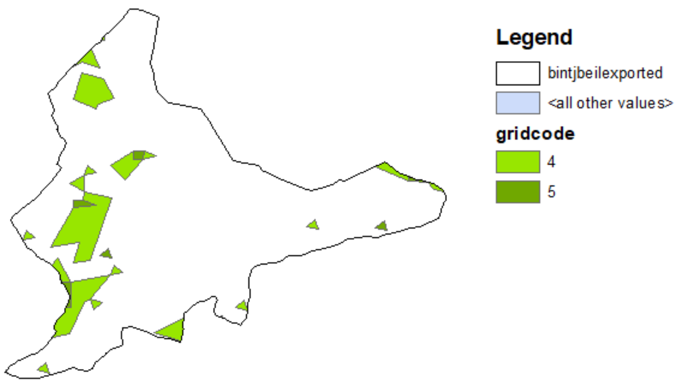


Figure 136. Reclassified map

Table 75. Classified areas for biomass technology

Classification		Biomass area (m^2)
From algebra map	Reclassification	
1.64 – 2.312	1	0
2.312 – 2.984	2	0
2.984 - 3.656	3	0
3.656 – 4.328	4	735 243
4.328 – 5	5	54 674

From the reference table [24], we collect the average power density for biomass energy: 0.45 W/m^2. We can say that by applying this technology, an energy ranges from 0-

0.45W can be produced on 1 m^2 area. Thus, we reclassify this power density scale into 5 classes as follows:

Table 76. Reclassified table of the power density

Reclassification scale	Power density scale (W/m^2)
1	0.09
2	0.18
3	0.27
4	0.36
5	0.45

To calculate the power for each area, we multiply the power density scale by the classified area of the applied technology.

Table 77. Power calculation for the biomass technology

Reclassification	Power density scale (W/m^2)	Biomass area (m^2)	Power density (W)	Power density (kW)
1	0.09	0	0	0
2	0.18	0	0	0
3	0.27	0	0	0
4	0.36	735 243	264 687	264
5	0.45	54 674	24 603	24
Total:		789 917	289 290	289

At this stage, we calculate the cost of installing the particular technology as follows:
The total cost to install a biomass power plant in the selected area is:
Power density (kw) X Average capital investment cost ($/kW)= $607 510.8522

Summary

Table 78. Summary table of example A

	Onshore wind	Offshore wind	CSP	PV	Geothermal	Biomass
Average power density (W/m^2)	1	3	10	9	20	0.45
Average capital investment cost ($/kW)	1 500	4 353	5 200	1 210	3 976	2 100
Total investment ($)	Not available	Not available	Not available	20 095 829	463 237 951	607 510
Power production (kW)	Not available	Not available	Not available	16 608	116 508	289

CHAPTER IX

CONCLUSIONS AND FUTURE WORK

In this study, renewable energy resources in Lebanon have been investigated to locate sites for prioritizing renewable energy development in the light of the available theoretical data on potential solar, wind, biomass, and geothermal energies.

Available renewable energy data have been transformed into GIS readable data. By using spatial analysis function in GIS based on weight computation by the AHP model, a resource map was generated for prioritizing the decision for renewable energy development in the suitable site. The generated resource map helped identify the highly, moderate and the least suitable site for the renewable energy development in Lebanon. It is important to stress that biomass and geothermal findings need refinement, but the proposed approach in what of main interest.

The output of this study can be used while making a decision to select the most suitable site for developing a renewable energy plant in Lebanon.

For further research, other parameters and criteria can be analyzed using AHP and GIS. Furthermore, the findings of this study will be set to develop an interactive energy planning platform and an interactive energy forum.

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Appendix

Appendix 1: Site Selection Criteria for Renewable Energy Resources in Lebanon Questionnaire

<u>Questionnaire:</u> Site Selection Criteria for Renewable Energy Resources in Lebanon

<u>About the Questionnaire</u>

This is a brief questionnaire conducted for the purpose of thesis research by Ms. Nour Baalbaki for an MS in Energy Studies at the American University of Beirut, under the supervision of Prof. Ali Bazzi. The thesis is tentatively entitled "Optimal Site Selection for Combined Renewable Energy Installations in Lebanon."

Selecting a suitable site is a crucial step toward developing a feasible utility-scale renewable energy project. It needs to consider many factors or criteria such as weather, geology, social acceptance, distance to infrastructure, etc, for each renewable energy technology. A literature review was completed, including a list of site selection criteria for the different renewable energy resources. Among these criteria, we need to select ones that fit Lebanon.

As an expert in renewable energy systems, you are kindly asked to provide your insight through this questionnaire. Participation in this questionnaire is completely voluntary. The questionnaire is anonymous, and your name, affiliation, and other specifics about your identity will not be stored or used. Any electronic submission of this questionnaire will be immediately and permanently deleted from the receiver's end after the anonymous questionnaire is downloaded. If you would like your name, affiliation, or other identifiers to be made public, please state your name, affiliation, and signature at the bottom of this page.

Below are the selected criteria from the literature review and a selected range is proposed. We are aiming at finding a selected range for Lebanon and ranking criteria according to the country specification. Other criteria might be added. Note that some criteria can be merged together.

<u>Definitions:</u>

1- **Proposed range:** We propose a certain range based on a very thorough literature review and as we expect fit for Lebanon.

2- ***Wind speed:*** or wind flow velocity, is a fundamental atmospheric quantity caused by air moving from high to low pressure, usually due to changes in temperature.

3- ***Wind power density:*** Including the effect of wind speed and wind speed distribution on the air density, wind power density is a composite indicator to evaluate the wind energy resources.

4- ***Wind direction and wind frequency:*** The arrangement of the generator sets location in wind farms depends on the distribution of wind power density direction and topographical features. In a wind rose diagram, a predominant wind direction or two opposite wind directions should be selected. The best effects would be obtained if the main wind direction is vertical to the mountain ridge. This is a qualitative indicator which could use the integers from 1 to 5 as the value of different quantitative ranks.

5- ***Turbulence intensity:*** Measures ratio of the standard deviation of the wind speed (m/s) to the average wind speed during a period of 10 min (m/s). It determines the fatigue load of the wind turbine and largely affects the service life of the units. This criterion applies the integrated turbulence above 30 m, which is evaluated by the dominant wind turbulence intensity and partial sector turbulence intensity.

6- ***Solar irradiance:*** is an essential criterion for large-scale solar power projects. Considerable amounts of solar energy play a significant role in producing more electrical power from available resources. Furthermore, the solar irradiation is composed into three components, the global (GHI), the diffuse (DHI) and the direct (DNI). Each component is used for a specific solar technology. As for concentrating solar power (CSP) plants, the DNI is the one that has to be assessed because it's the one that can be concentrated, while for the PV we have to assess and map the amount of the GHI.

7- ***Proximity to roads:*** The site should be accessible by roads for the transportation of the system components, construction materials, and other equipment.

8- ***Proximity to transmission lines:*** A critical issue in keeping costs down in building a wind/solar farm is minimizing the amount of transmission infrastructure that has to be installed. High voltage lines can cost thousands of dollars per mile. Whenever possible, availability and access to existing lines should be considered in selecting a site.

9- ***Distance to shore:*** Distance from the shore will influence the maintenance cost and transportation and installation costs. Different from the distance from the channel and anchorage, the farther the distance from shore, the worse the alternative is.

10- ***Proximity to urban areas:*** With respect to the distance to urban areas, certain studies consider locations that are further away from cities more suitable for renewable energy development to avoid negative environmental impact on urban development and to avoid not in my back yard (NIMBY) opposition. On the other hand, other studies indicate that sites near cities have more economic advantages (minimizing the distance electricity would have to travel and reducing associated line-loss and transmission expenses).

11- ***Distance to rural communities:*** Renewable energy is considered as a potentially significant new source of jobs and rural growth in rural areas, and a means of addressing environmental and energy security concerns. It is found out that while RE indeed represents an opportunity for stimulating economic growth in hosting communities, it also requires a complex and flexible policy framework and a long-term strategy. Making a positive connection between RE development and local economic growth will require more coherent strategies, the right set of local conditions, and a place-based approach to deployment.

12- ***Population density:*** locating the power plants nearby the adequate consumer is a key factor that should be taking into account. Establishing a farm near the highly populated cities is an advantage.

13- ***Slope:*** Steep slopes make construction difficult and more expensive. With the increase of the slope the complexity of the design increases, which often leads to a proportional increase in costs.

14- ***Elevation:*** Elevation is one of the effective factors in industrial location. It has a regression correlation with coefficient of 95% with temperature and precipitation. The height of the region from sea level is proportional with atmosphere thickness inversely. Thick atmosphere implies more concentration of the compounds or absorption or reflection factors. Since the coarser and thicker materials are collected in the lower classes, the atmosphere is thinner on the tops of the mountains. The atmosphere thickness and compounds control surge power in addition to short wave energy of the sun. Therefore, high lands have more potential than low lands because of receiving high energy. However, high altitude areas have higher transportation cost and are not preferable.

15- ***Aspect:*** It identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors in GIS. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1.

16- ***Land ownership:*** Landowners, both private and public, will expect to be compensated for any wind energy development that occurs on their land. Royalty or lease agreements will need to be discussed with all parties involved. Roads, transmission equipment, maintenance infrastructure, turbines, and the like all need to be considered.

17- ***Foundation and soil quality:*** Wind-turbine foundation design requires appropriate geotechnical studies, namely knowledge of loads, and correct estimates of stresses and settlement, which must be calculated in geotechnical engineering studies. Geotechnical studies must also be conducted to assess soil properties for a given site with reference to locally available construction standards and regulations. An effective design requires a very good knowledge of the soil characteristics of the site.

18- ***Land use and land cover:*** Land use is the main basis and the most influential criteria for urban-rural planning and the distribution of various land-use types leads to considerable constraints in urban and rural planning. Certain land use types have restricted use. These areas may not be used because of economic and environmental interests.

Land cover represents all the physical and biological material on the Earth's surface that makes an area favorable or not for the installation of a power plant.

19- ***Noise:*** Noise from wind turbines comes primarily from the rotor blades as they slice through the air. Although wind machines built recently make substantially less noise than earlier models, noise from wind machines is potentially a problem if wind farms are sited too close to residences.

20- ***Bird strikes:*** Birds can fly into fast-moving rotor blades of wind machines and be killed. While evidence to date indicates that birds generally learn to avoid the spinning rotors, some problems with bird strikes have been noted.

21- ***Visual impacts:*** The presence of wind turbines produce changes in views and skylines, and thus have a visual impact on the area in which they are cited. Visual impacts may be an especially important consideration if the turbines are to be located in pristine or wilderness areas. The access roads and power lines needed for grid-connected turbines can cause additional aesthetic impacts.

22- ***Water depth:*** Water depth is a distinguishing factor for the site selection of offshore wind farm owing to the offshore nature, and this factor will have impact on the installation of the wind turbine and finally influence the cost of installation. It is very hard to install the wind turbine in the site with large water depth.

23- ***Distance to shore and waterways:*** The offshore wind farm located close to the shore especially in busy waterways may have significantly impact on the maritime safety. Maritime safety is the key issue for offshore wind farm in the busy waterway. As there are many ships navigating, anchoring or fishing in the nearby waterways, the construction of offshore wind farm will occupy the navigable waterways and also have impact on the radar and very high frequency, which is used for communication of collision avoidance for the ships. Moreover, the distance from the shore will have impact on the electric and grid connection.

24- ***Water availability:*** Water resources are also a crucial criterion for site assessment of solar power plants, especially in arid regions where PV panels need to be cleaned in order to keep higher efficiency. CSP needs water for cleaning and cooling.

		Renewable energy technologies						
		Onshore Wind	Offshore Wind	Concentrated Solar Power (CSP)	Photovoltaic Panels (PV)	Biomass	Geothermal	
#	Criterion							Comments
1	Wind speed	Applicable? ☐Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: > 5m/s Your suggested range:	Proposed range: > 5m/s Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
2	Wind power density	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: >300 W/m^2 Your suggested range:	Proposed range: >300 W/m^2 Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	

3	Wind direction and wind frequency	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
4	Turbulence intensity	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
5	Solar irradiance	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: exclude areas with annual DNI<1100 kWh/m Your suggested range:	Proposed range: exclude areas with annual GHI<1700 kWh/m Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
6	Proximity to roads	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: >500m and <10km Your suggested range:	Proposed range: X Your suggested range:	Proposed range: >500m and <10km Your suggested range:	Proposed range: >500m and <10km Your suggested range:	Proposed range: >300m and <100km Your suggested range:	Proposed range: Buffer zone within 100m Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
7	Proximity to transmission lines	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: >240 m and <85 km Your suggested range:	Proposed range: X Your suggested range:	Proposed range: >240 m and <85 km Your suggested range:	Proposed range: >240 m and <85 km Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	

		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
8	Distance from shore	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: more than 10 km Your suggested range:	Proposed range: X Your suggested range:	Proposed range: distance to shoreline>1000m Your suggested range:	Proposed range: distance to shoreline>1000m Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
9	Proximity to urban areas	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: >500m and <200 km Your suggested range:	Proposed range: X Your suggested range:	Proposed range: >500m and <200 km Your suggested range:	Proposed range: >500m and <200 km Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
10	Distance to rural communities	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐No	Applicable? ☐ Yes, ☐ No	Applicable? ☐Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: > 1km Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: 500m buffer size Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
11	Population density	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: middle population density areas (from 50 to 300 people/km2) Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
12	Slope	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐Yes, ☐ No	
		Proposed range: < 30% Your	Proposed range: <30% Your	Proposed range: <2.1° Your suggested	Proposed range: <15° Your suggested	Proposed range: <15° Your	Proposed range: <15° Your suggested	

		suggested range:	suggested range:	range:	range:	suggested range:	range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
13	Elevation	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range:>100m Your suggested range:	Proposed range:>100m Your suggested range:	Proposed range: <1500m Your suggested range:	Proposed range: <1500m Your suggested range:	Proposed range: from 0 to 500 m Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
14	Aspect	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: south, sout-east, south west Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
15	Land ownership	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: acceptance Your suggested range:	Proposed range: acceptance Your suggested range:	Proposed range: acceptance Your suggested range:	Proposed range: acceptance Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
16	Foundation and soil quality	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: suitable foundation Your suggested range:	Proposed range: suitable foundation Your suggested range:	Proposed range: soft soil Your suggested range:	Proposed range: soft soil Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
17	Land use and land cover	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: Buffer zones within 1 km from protected areas. Distance from airports: 2.5 km	Proposed range: Buffer zones within 1 km from protected areas. Distance from airports: 2.5 km Your suggested	Proposed range: Buffer zones within 1 km from protected areas. Your suggested range:	Proposed range: Buffer zones within 1 km from protected areas. Your suggested range:	Proposed range: Buffer zones within 1 km from protected areas. Your suggested range:	Proposed range: area with minimum vegetation cover density Your suggested range:	

		Your suggested range:	range:					
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
18	Noise	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:.	Rank:	
19	Bird strikes	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: 250 m away from protected areas Your suggested range:	Proposed range: 250 m away from protected areas Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
20	Visual impact	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
21	Water depth	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: areas with water depth between 5m and 60m Your suggested range:	Proposed range: areas with water depth between 5m and 60m Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	.
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
22	Distance to waterways	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	

		Proposed range: Areas within 100m-10km of rivers Your suggested range:	Proposed range: Areas within 100m-10km of rivers Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: away from water bodies Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
23	Water availability	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	Proposed range: water availability within 100m Your suggested range:	Proposed range: water availability within 100m Your suggested range:	Proposed range: X Your suggested range:	Proposed range: X Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
24	Other criteria:	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
25	Other criteria:	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	
26	Other criteria:	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	Applicable? ☐ Yes, ☐ No	
		Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	Proposed range: Your suggested range:	
		Rank:	Rank:	Rank:	Rank:	Rank:	Rank:	