Planning and developing a renewable energy project in south of Algeria: using multi-criteria decision analysis
Abstract

The observation of the current energy situation in Algeria indicates a great increase in energy demand and a depletion of fossil fuels. Moreover, Energy production using fossil resources is accompanied with large emissions of greenhouse gases. In this work, proposed renewable energy technologies are studied to select the suitable type of energy in south of Algeria, particularly Wilaya of Ouargla. Multi-criteria decision analysis (MCDA) methods are used to deal with the complexity of selecting and ranking the different renewable energy technologies from the point of view of their compatibility with humanity's sustainable development (technical, economic, social and environmental). The main obtained results show that Solar PV is, in general, the best option and it can be also improved by combined with another type of renewable energy.

Key words: South of Algeria, renewable energy, MCDA

Résumé:

L'observation de la situation actuelle de l'énergie en Algérie indique une forte augmentation de la demande d'énergie et d'un épuisement des combustibles fossiles. En plus de ça, la production d'énergie par utilisation des sources fossiles est accompagnée d'importantes émissions de gaz à effet de serre. Dans ce travail, les technologies proposées d'énergie renouvelable sont étudiées pour sélectionner le type d'énergie le plus approprié dans le sud d'Algérie, particulièrement Wilaya de Ouargla. Les méthodes d'analyse multicritères de décision (MCDA) sont utilisées pour traiter la complexité de la sélection et le classement des différentes technologies d'énergie renouvelable à partir du point de vue de leurs compatibilités avec le développement durable de l'humanité (technique, économique, social et environnemental). Les principaux résultats obtenus montrent que solaire PV est en général la meilleure option et il peut également être amélioré par la combinaison avec un autre type d'énergie renouvelable.

Mots clés : Sud de l'Algérie, les énergies renouvelables, MCDA
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<td></td>
</tr>
<tr>
<td>C</td>
<td>Criteria</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Speed of light: $3 \times 10^8$</td>
<td>m/s</td>
</tr>
<tr>
<td>E</td>
<td>Energy</td>
<td>J</td>
</tr>
<tr>
<td>H</td>
<td>Planck’s constant: $6.626 \times 10^{-34}$</td>
<td>Js</td>
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<td>q</td>
<td>Indifference thresholds Veto</td>
<td></td>
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<td>p</td>
<td>Preference thresholds</td>
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<td>S</td>
<td>At least as good as</td>
<td></td>
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<td>Sj</td>
<td>Least mean square</td>
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<td>V</td>
<td>Veto threshold</td>
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</tr>
<tr>
<td>W</td>
<td>Weight</td>
<td>%</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Wave length</td>
<td>m</td>
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</tbody>
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### Abbreviation

- **CCGT** Combined Cycle Gas Turbine
- **CSP** Concentrating Solar Power
- **CCS** Carbon Capture Storage
- **CCUS** Carbon Capture Utilization and Storage
- **LCOE** Levelised Cost Of Energy
- **LNG** Liquefied Natural Gas
- **RNS** Renewable Energy Sources

$L$/MWh
Introduction General
**Introduction**

Energy is one of the most important factors in modern society’s development. With the need of energy in all sectors, the demand is continuously increase. Producing energy, such as electricity generation, is assured by a variety of technologies that based on energy source; fossil like oil, gas or coal and renewable like solar, wind or hydro. Nowadays, fossil fuels are the most utilised sources, about 94% of the total energy production (bp, 2013). As a number of developing countries, the main source of Algerian’s income is by exporting hydrocarbons. Furthermore, it is the main means of energy production as well. However, in addition to depletion of fossil fuels, they also have grave influence on human and environment. Using Renewable Energy Sources (RES) can extend the lifetime of fossil energy sources, increase security of supply, boost employment, and reduce local and regional pollution. Recently, political support for renewable energies has been growing continuously at the national and international level and most scientists now agree that the Middle East and North Africa are perfectly placed to play a leading role in the lucrative future solar and wind power industries. Algeria enjoys a relatively high abundance of sunshine, solar radiation, moderate wind speeds, biomass and geothermal energy resources. "Sustainable development means the satisfaction of present needs without compromising the ability of future generations to meet their own needs" (WCED, 2009). The goals of energy policy towards sustainable development are founded on three pillars namely: energy security and economic growth, environmental protection and social responsibility. Selecting the best alternative from a number of different renewable technologies is a very difficult stuff due to the diversity of the indicators (criteria) that are used to assess the technologies or alternatives. This work is divided into four chapters that are enumerated below:

**Chapter 1** is an overview of the energy situation in the world and Algeria is introduced. **Chapter 2** contains details about renewable energies, such as solar, geothermal, biomass, hydro and wind also their present and future of in Algeria. **Chapter 3** presents the definition of multi-criteria decision analysis (MCDA) methods and addresses the main steps for this method. **Chapter 4** is a case of study (case of Ouargla) where, we applied two MCDA methods; ELECTREE and multi utility, to choose the alternative renewable energy project between solar, wind, geothermal and biomass in addition to hybrid techniques.
Chapter 1: Energy and environmental context
Chapter 1: Energy and environmental context

Energy is identified as a fundamental part in any country development process. Energy produced and used in ways that support human development in all its social, economic and environmental dimensions is what is meant by sustainable energy. The goals of energy policy towards sustainable development are founded on three pillars namely: energy security and economic growth (Profit), environmental protection (Planet) and social responsibility (People). Using Renewable Energy Sources (RES) can extend the lifetime of fossil energy sources, increase security of supply, boost employment, reduce local and regional pollution, and reduce sources of climate-damaging CO2. The important economical changes undertaken these last years on the national and the international levels, led Algeria to start working on structural reforms aiming to a progressive adaptation, notably in the energy sector (fossil and renewable energies), so it will be comply with a free, open and competitive economy. In this perspective, the Algerian government intends to promote and speed up a greater and more diversified participation of the energy Private-sector for investments development, technologies acquisitions and access to foreign markets. This new policy required changes of the legal and institutional frameworks that the government has pursued, on both the global and sector-based levels to overcome challenges facing the efforts to increase renewable energy use. The setting up of a specific and competitive energy tax system (for renewables), combined to the formulation of more inciting investment conditions, will give a new impulse to the energy sector activities development.

1.1 Energy and environment

In covering the society energy needs, the best possible balance should be chosen between three key dimensions: competitiveness, security of supply, and the environment and climate. In other words; how much are we ready to pay for our energy? How much energy does society require? And what impact on the environment are we willing to accept? This energy triangle illustrates the advantages and disadvantages of each energy source and the need for a mix of complementary energy sources in power production. Currently, no single energy source is optimal from all dimensions.
1.2 fossil energy resources

1.2.1 Coal

Even with its poor environmental credentials, coal remains an important contributor to energy supply in many countries. It is the most used fossil fuel around the world, and more than 75 countries have coal deposits. The current share of coal in global power generation is over 40%, but it is expected to decrease in the coming years, while the actual coal consumption in absolute terms will grow. Although countries in Europe, and to some extent North America, are trying to shift their consumption to alternative sources of energy, any reductions are more than offset by the large developing economies, primarily in Asia, which are powered by coal and have significant coal reserves. China alone now uses as much coal as the rest of the world.
The continuing popularity of coal becomes particularly obvious when compared to the current production figures with those from 20 years ago. While the global reserves of coal have decreased by 14% between 1993 and 2011, the production has gone up by 68% over the same time period. Compared to the 2010 survey, the most recent data shows that the proved coal reserves have increased by 1% and production by 16%. The future of coal depends primarily on the advance of clean coal technologies to mitigate environmental risk factors, CO2 emissions, in particular. Today Carbon Capture Utilization and Storage (CCS/CCUS) is the only large-scale technology which could make a significant impact on the emissions from fossil fuels. It is, however, still at the pilot stage and its future is uncertain, mainly because of the high costs and efficiency penalty. Coal is playing an important role in delivering energy access, because it is widely available, safe, reliable and relatively low cost. One of the major challenges facing the world at present is that approximately 1.2 billion people live without any access to modern energy services. Access to energy is a fundamental pre-requisite for modern life and a key tool in eradicating extreme poverty across the globe.

Coal resources exist in many developing countries, and this report demonstrates that many countries with electricity challenges, particularly those in Asia and southern Africa, are able to access coal resources in an affordable and secure way to fuel the growth in their electricity supply. Coal will therefore play a major role in supporting the development of base-load electricity where it is most needed. Coal-fired electricity will be fed into national grids and it will bring energy access to millions, thus facilitating economic growth in the developing world.
Table 1.1: Coal reserves; top 5 countries (World Energy Council 2013)

<table>
<thead>
<tr>
<th>Country</th>
<th>Reserves (Mt)</th>
<th>Production (Mt)</th>
<th>2011 R/P</th>
<th>1993 R/P</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States of America</td>
<td>237295</td>
<td>168391</td>
<td>1092</td>
<td>858</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>157010</td>
<td>168700</td>
<td>327</td>
<td>304</td>
<td>&gt;100</td>
</tr>
<tr>
<td>China</td>
<td>114500</td>
<td>80150</td>
<td>3384</td>
<td>1150</td>
<td>34</td>
</tr>
<tr>
<td>Australia</td>
<td>76400</td>
<td>63658</td>
<td>398</td>
<td>224</td>
<td>&gt;100</td>
</tr>
<tr>
<td>India</td>
<td>60600</td>
<td>48963</td>
<td>516</td>
<td>263</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Rest of World</td>
<td>245725</td>
<td>501748</td>
<td>1805</td>
<td>1675</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Global total</td>
<td><strong>891530</strong></td>
<td><strong>1 031 610</strong></td>
<td><strong>7520</strong></td>
<td><strong>4474</strong></td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

Table 1.2: Benefits and drawbacks of coal (World Energy Council 2013)

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide geographic distribution</td>
<td>High emissions of CO2, particulates and other pollutants</td>
</tr>
<tr>
<td>Stable and predictable costs</td>
<td>Not suitable for peaking generation units</td>
</tr>
<tr>
<td>New technologies for coal improve efficiency and environmental performance</td>
<td>CCS/CCUS have negative impact on thermal plant efficiency</td>
</tr>
</tbody>
</table>

Figure 1.3: global oil reserves in the world (World Energy Council 2013)
1.2.2 Oil

The oil crisis in the 1970s and 1980s resulted in long queues outside petrol stations and the skyrocketing price of oil. In the following years, heated discussions about “peak oil” were based on the expectation of the world running out of oil within a few decades. However since oil is a finite resource this issue will return in the future. Global oil reserves are almost 60% larger today than 20 years ago, and production of oil has gone up by 25%. If the unconventional oil resources, including oil shale, oil sands, extra heavy oil and natural bitumen are taken into account, the global oil reserves will be four times larger than the current conventional reserves. Oil still remains the premier energy resource with a wide range of possible applications. Its main use however, will be shifting towards transport and the petrochemical sector. In future oil’s position at the top of the energy ladder will face a strong challenge from other fuels such as natural gas. The oil resource assessments have increased steadily between 2000 and 2009, and about a half of this increase is due to the reclassification of the Canadian oil sands and the revisions undertaken in major OPEC countries: Iran, Venezuela and Qatar. Compared to the 2010 survey, the proved oil reserves increased by 37% and production by 1%. Oil is a mature global industry which offers the market participants opportunities for good economic returns. The balance between returns on capital and host countries’ interests is a delicate matter. A number of countries, for political reasons, have limited the access of international companies.

Table 1.3: Crude oil reserves: top 5 countries (World Energy Council 2013)

<table>
<thead>
<tr>
<th>Country</th>
<th>Reserves (Mt)</th>
<th>Production (Mt)</th>
<th>2011 R/P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td>1993</td>
<td>2011</td>
</tr>
<tr>
<td>Venezuela</td>
<td>40450</td>
<td>9842</td>
<td>155</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>36500</td>
<td>35620</td>
<td>526</td>
</tr>
<tr>
<td>Canada</td>
<td>23598</td>
<td>758</td>
<td>170</td>
</tr>
<tr>
<td>Iran</td>
<td>21359</td>
<td>12700</td>
<td>222</td>
</tr>
<tr>
<td>Iraq</td>
<td>19300</td>
<td>13417</td>
<td>134</td>
</tr>
<tr>
<td>Rest of World</td>
<td>82247</td>
<td>68339</td>
<td>2766</td>
</tr>
</tbody>
</table>
Table 1.4: Benefits and Drawbacks of Oil (world energy council)

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currently indispensable for road transport and petrochemical industries</td>
<td>High price volatility</td>
</tr>
<tr>
<td>Leading tradable commodity</td>
<td>Geopolitical tensions related to areas of greatest reserves</td>
</tr>
<tr>
<td>Flexible, easy to transport fuel</td>
<td>Market dominated by leading oil producers (OPEC and large NOCs)</td>
</tr>
</tbody>
</table>

Figure 1.4: global natural gas reserves (World Energy Council 2013)

1.2.3 Natural gas

Natural gas is yet another fossil fuel resource that will continue making significant contribution to the world energy economy. The cleanest of all fossil-based fuels, natural gas is plentiful and flexible. It is increasingly used in the most efficient power generation technologies, such as, Combined Cycle Gas Turbine (CCGT) with conversion efficiencies of about 60%. The reserves of conventional natural gas have grown by 36% over the past two decades and its production by 61%. Compared to the 2010 survey, the proved natural gas reserves have grown by 3% and production by 15%. The exploration, development and transport of gas usually requires significant upfront investment. Close coordination between
investment in the gas and power infrastructure is necessary. In its search for secure, sustainable and affordable supplies of energy, the world is turning its attention to unconventional energy resources. Shale gas is one of them. It has turned upside down the North-American gas markets, and is making significant strides in other regions. The emergence of shale gas as a potentially major energy source can have serious strategic implication for geopolitics and the energy industry.

Table 1.5: Natural gas reserves: top 5 countries (World Energy Council 2013)

<table>
<thead>
<tr>
<th>Country</th>
<th>Reserves (Mt)</th>
<th>Production (Mt)</th>
<th>R/P Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russian Federation</td>
<td>47 750</td>
<td>48 160</td>
<td>604</td>
</tr>
<tr>
<td>Iran</td>
<td>33 790</td>
<td>20 659</td>
<td>670</td>
</tr>
<tr>
<td>Qatar</td>
<td>25 200</td>
<td>7 079</td>
<td>75</td>
</tr>
<tr>
<td>Turkmenistan</td>
<td>25 213</td>
<td>2 860</td>
<td>150</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>8 028</td>
<td>5 260</td>
<td>77</td>
</tr>
<tr>
<td>Rest of World</td>
<td>69 761</td>
<td>57 317</td>
<td>2 407</td>
</tr>
</tbody>
</table>

Table 1.6: Benefits and Drawbacks of natural gas (World Energy Council 2013)

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleanest of fossil fuels</td>
<td>Fields increasingly off-shore and in remote areas</td>
</tr>
<tr>
<td>Flexible and efficient fuel for power generation</td>
<td>High upfront investment requirement for transport and distribution system</td>
</tr>
<tr>
<td>Increasing proved reserves (reassessments and shale gas)</td>
<td>Increasingly long supply routes and high cost of Infrastructure</td>
</tr>
</tbody>
</table>

1.2.4 Oil and natural gas in Algeria

Algeria has large reserves of oil and natural gas and greatly depends on these resources to generate export earnings. The oil and gas sector accounts for 45.9% of Algerian GDP. Total oil and gas exports accounted for nearly 98% of the total volume of exports for 2007. With an export turnover of nearly 56.1 billion USD in 2010 realized by the Sonatrach Company, Algeria was the fourth largest exporter of liquefied natural gas (LNG) in the world, the third largest exporter of liquefied petroleum gas (LPG) and the fifth largest exporter of natural gas.
1.2.5 Geographical Distribution of Hydrocarbon Reserves

Nearly all of the reserves discovered to date have been found in the eastern part of the Sahara (Fig. 4). Analyzing this geographical distribution by splitting the country into a number of more or less homogeneous oil regions (Fig. 5) we find the distribution is as given below.

- 67% of the initial oil and gas in place are contained in the provinces of Oued Mya and Hassi Messaoud, where the two giant fields of Hassi R’mel (gas) and Hassi Messaoud (oil) are situated.
- The Illizi Basin occupies third place with 14% of the initial reserves.
- This is followed by the basins of RhourdeNouss (9%), Ahnet-Timimoun (4%) and finally Ghadamés, which contains only 3% of current reserves. If we examine the geographical location of reserves by hydrocarbon type (Fig. 6) the following facts are revealed.
- The province of Hassi-Messaoud-Dahar, associated with one of the most important tectonic events in the Sahara, has 71% of Algeria's oil reserves.
- The province of OuedMya is basically a Mesozoic basin, which contains 50% of Algeria's total gas reserves, and some oil (6%).
- The geological sequence in the Illizi Basin is dominated by Palaeozoic rocks, and contains roughly the same proportion of oil (15%) and gas (14%) reserves.
- The RhourdeNouss and Ghadamés basins are more geologically complex (comprising Palaeozoic and Mesozoic rocks) and contain 19% of Algeria's proven gas (mainly at Rhourde Nouss) and nearly half of the probable and possible gas total. In addition, these basins contain about 8% of the country's oil.
- The Palaeozoic Ahnet-Timimoun Basin only contains gas (13%), with half of the reserves still classed as probable and possible.
- The reserves discovered in the other provinces are currently negligible (less than 4% in total) but these accumulations, when compared to the exploration maturity of the regions in which they occur, indicate significant hydrocarbon potential throughout Algeria. The concentration of hydrocarbon accumulations in the eastern Sahara reflects our current technical knowledge, the historical evolution of exploration efforts and variations in relative drilling density between different regions within Algeria.

1.3 Uranium and Nuclear

The nuclear industry has a relatively short history: the first nuclear reactor was commissioned in 1954. Uranium is the main source of fuel for nuclear reactors. Worldwide output of uranium has recently been on the rise after a long period of declining production caused by oversupply following nuclear disarmament. The present survey shows that total identified uranium resources have grown by 12.5% since 2008 and they are sufficient for over 100 years of supply based on current requirements. Total nuclear electricity production has been growing during the past two decades and reached an annual output
of about 2 600TWh by the mid-2000s, although the three major nuclear accidents have slowed down or even reversed its growth in some countries. The nuclear share of total global electricity production reached its peak of 17% by the late 1980s, but since then it has been falling and dropped to 13.5% in 2012. In absolute terms, the nuclear output remains broadly at the same level as before, but its relative share in power generation has decreased, mainly due to Fukushima nuclear accident. Japan used to be one of the countries with a high share of nuclear (30%) in its electricity mix and high production volumes. Today, Japan has only two of its 54 reactors in operation. The rising costs of nuclear installations and lengthy approval times required for new construction have had an impact on the nuclear industry. The slowdown has not been global, as new countries, primarily in the rapidly developing economies in the Middle East and Asia, are going ahead with their plans to establish a nuclear industry.

Table 1.7: Nuclear Power: top 5 countries (World Energy Council 2013)

<table>
<thead>
<tr>
<th>Country</th>
<th>Installed Capacity (MW)</th>
<th>Actual Generation (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td>1993</td>
</tr>
<tr>
<td>United States of America</td>
<td>98 903</td>
<td>99 041</td>
</tr>
<tr>
<td>France</td>
<td>63 130</td>
<td>59 032</td>
</tr>
<tr>
<td>Japan</td>
<td>38 009</td>
<td>38 038</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>23 643</td>
<td>19 843</td>
</tr>
<tr>
<td>Korea (Republic)</td>
<td>20 718</td>
<td>7 615</td>
</tr>
<tr>
<td>Rest of World</td>
<td>119 675</td>
<td>116 726</td>
</tr>
<tr>
<td>Global total</td>
<td>364 078</td>
<td>340 295</td>
</tr>
</tbody>
</table>

Table 1.8: Benefits and drawbacks of nuclear power (World Energy Council 2013)

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>High efficiency</td>
<td>High CAPEX and rising compliance costs</td>
</tr>
<tr>
<td>Moderate and predictable cost of electricity</td>
<td>Public concerns about operation and final waste disposal</td>
</tr>
<tr>
<td>over the service life</td>
<td></td>
</tr>
<tr>
<td>No CO2 during life cycle</td>
<td>Liabilities in case of nuclear accident</td>
</tr>
</tbody>
</table>

1.3.1 The Future of Nuclear Power

Energy systems of the future will require energy sources that can produce large amounts of electricity without emitting greenhouse gases. Nuclear power is an energy source that has the potential to meet these requirements. European research plays a key role in the field of nuclear technology and focuses on,
among other things, waste management optimisation and fuel conservation. The framework for future nuclear power has also been established through several international organisations and networks related to research and development. Existing reactors are unable to use more than a small portion of the available nuclear fuel. The resulting energy surplus can only be captured if spent fuel is reprocessed and recycled into the fuel cycle. Improving reactor design or providing better options for reprocessing and reusing nuclear fuel would reduce hazardous waste levels and result in better use of available uranium resources.

1.3.2 Nuclear power in Algeria

Algeria possesses a small civil nuclear research program, and currently operates two research Reactors under the supervision of the Atomic Energy Commission.

1.4 Solar PV

Solar energy is the most abundant energy resource and it is available for use in its direct (solar radiation) and indirect (wind, biomass, hydro, ocean etc.) forms. About 60% of the total energy emitted by the sun reaches the Earth’s surface. Even if only 0.1% of this energy could be converted at an efficiency of 10%, it would be four times larger than the total world’s electricity generating capacity of about 5 000GW. The statistics about solar PV installations are patchy and inconsistent. The table below presents the values for 2011 but comparable values for 1993 are not available.

The use of solar energy is growing strongly around the world, in part due to the rapidly declining solar panel manufacturing costs. For instance, between 2008–2011 PV capacity has increased in the USA from 1 168MW to 5 171MW, and in Germany from 5877 MW to 25039MW. The anticipated change in national and regional legislation regarding support for renewables is likely to moderate this growth.

| Table 1.9: League tables reserves top 5 countries (World Energy Council 2013) |
|-------------------------------|-----------------|-----------------|
| Country                       | Installed Capacity (MW) | Actual Generation (GWh) |
| Germany                       | 25 039          | 19 340          |
| Italy                         | 12 773          | 10 730          |
| United States of America      | 5 171           | 5 260           |
| Japan                         | 4 914           | 5 160           |
| Spain                         | 4 332           | 7 386           |
| Rest of World                 | 16 621          | 5 002           |
| Global total                  | **68 850**      | **52 878**      |
### 1.5 Hydro Power

Hydro power provides a significant amount of energy throughout the world and is present in more than 100 countries, contributing approximately 15% of the global electricity production. The top 5 largest markets for hydro power in terms of capacity are Brazil, Canada, China, Russia and the United States of America. China significantly exceeds the others, representing 24% of global installed capacity. In several other countries, hydro power accounts for over 50% of all electricity generation, such as Iceland, Nepal and Mozambique. During 2012, an estimated 27–30GW of new hydro power and 2–3GW of pumped storage capacity was commissioned. In many cases, the growth in hydro power was facilitated by the lavish renewable energy support policies and CO2 penalties. Over the past two decades the total global installed hydro power capacity has increased by 55%, while the actual generation by 21%. Since the last survey, the global installed hydro power capacity has increased by 8% but the total electricity produced dropped by 14%, mainly due to water shortages.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>High reliability, no moving parts</td>
<td>Intermittency</td>
</tr>
<tr>
<td>Quick installation and dismantling</td>
<td>Grid connection challenges</td>
</tr>
<tr>
<td>Suitable solution for remote areas</td>
<td>Use of toxic materials</td>
</tr>
</tbody>
</table>

#### Table 1.11: Hydro Power: top 5 countries Hydro (World Energy Council)

<table>
<thead>
<tr>
<th>Country</th>
<th>2011 Installed Capacity (MW)</th>
<th>1993 Installed Capacity (MW)</th>
<th>2011 Actual Generation (GWh)</th>
<th>1993 Actual Generation (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>231 000</td>
<td>44 600</td>
<td>714 000</td>
<td>138 700</td>
</tr>
<tr>
<td>Brazil</td>
<td>82 458</td>
<td>47 265</td>
<td>428 571</td>
<td>252 804</td>
</tr>
<tr>
<td>United States of America</td>
<td>77 500</td>
<td>74 418</td>
<td>268 000</td>
<td>267 326</td>
</tr>
<tr>
<td>Canada</td>
<td>75 104</td>
<td>61 959</td>
<td>348 110</td>
<td>315 750</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>49 700</td>
<td>42 818</td>
<td>180 000</td>
<td>160 630</td>
</tr>
<tr>
<td>Rest of World</td>
<td>430 420</td>
<td>338 204</td>
<td>828 437</td>
<td>1 150 750</td>
</tr>
<tr>
<td>Global total</td>
<td>946 182</td>
<td>609 264</td>
<td>2 767 118</td>
<td>2 285 960</td>
</tr>
</tbody>
</table>
### Benefits vs. Drawbacks

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low operating costs</td>
<td>High CAPEX</td>
</tr>
<tr>
<td>No waste or CO2 emissions</td>
<td>Significant land requirement for large plants with dams/lakes</td>
</tr>
<tr>
<td>Simple proven technology</td>
<td>Public resistance due to relocation or microclimate effects</td>
</tr>
</tbody>
</table>

#### 1.6 Wind

Wind is available virtually everywhere on earth, although there are wide variations in wind strengths. The total resource is vast; estimated to be around a million GW ‘for total land coverage’. If only 1% of this area was utilized, and allowance made for the lower load factors of wind plants (15–40%, compared with 75–90% for thermal plants) that would still correspond, roughly, to the total worldwide capacity of all electricity-generating plants in operation today. World wind energy capacity has been doubling about every three and a half years since 1990. Total capacity at the end of 2011 was over 238GW and annual electricity generation around 377TWh, roughly equal to Australia’s annual electricity consumption.

China, with about 62GW, has the highest installed capacity while Denmark, with over 3GW, has the highest level per capita. Wind accounts for about 20% of Denmark’s electricity production. It is difficult to compare today’s numbers with those two decades ago, as measuring methodologies and tools are different. As governments begin to cut their subsidies to renewable energy, the business environment becomes less attractive to potential investors. Lower subsidies and growing costs of material input will have a negative impact on the wind industry in recent years.

**Table 1.13: Wind power; top 5 countries (World Energy Council 2013)**

<table>
<thead>
<tr>
<th>Country</th>
<th>Installed Capacity (MW)</th>
<th>Actual Generation (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td>1993</td>
</tr>
<tr>
<td>China</td>
<td>62,364</td>
<td>15</td>
</tr>
<tr>
<td>United States of America</td>
<td>46,919</td>
<td>1,814</td>
</tr>
<tr>
<td>Germany</td>
<td>29,071</td>
<td>650</td>
</tr>
<tr>
<td>Spain</td>
<td>21,673</td>
<td>52</td>
</tr>
<tr>
<td>India</td>
<td>15,880</td>
<td>40</td>
</tr>
<tr>
<td>Rest of World</td>
<td>62,142</td>
<td>-</td>
</tr>
<tr>
<td>Global total</td>
<td><strong>238,049</strong></td>
<td>-</td>
</tr>
</tbody>
</table>
### Table 1.14: Benefits and Drawbacks of Wind Power (World Energy Council 2013)

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple technology, quick installation and dismantling of onshore installations</td>
<td>Intermittency</td>
</tr>
<tr>
<td>No fuel or waste costs</td>
<td>Grid integration challenges</td>
</tr>
<tr>
<td>Clean solution for remote areas</td>
<td>Reliance on subsidies</td>
</tr>
</tbody>
</table>

### 1.7 Bioenergy and Waste

Bioenergy is a broad category of energy fuels manufactured from a variety of feed stocks of biological origin and by numerous conversion technologies to generate heat, power, liquid biofuels and gaseous biofuels. The term “traditional biomass” mainly refers to fuel wood, charcoal, and agricultural residues used for household cooking, lighting and space-heating in developing countries. The industrial use of raw materials for production of pulp, paper, tobacco, pig iron so on, generates by products such as bark, wood chips, black liquors, agricultural residues, which can be converted to bioenergy. The share of bioenergy in TPES has been estimated at about 10% in 1990. Between 1990 and 2010 bioenergy supply has increased from 38 to 52EJ as a result of growing energy demand. New policies to increase the share of renewable energy and indigenous energy resources are also driving demand.

### Table 1.15: Benefits and Drawbacks of Bioenergy and Waste (World Energy Council 2013)

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic resource</td>
<td>Transportation and processing implications</td>
</tr>
<tr>
<td>Proven simple combustion technologies</td>
<td>Emissions of NOx and Sox</td>
</tr>
<tr>
<td>Biofuels as alternative for transport</td>
<td>Energy – Water/food aspects</td>
</tr>
</tbody>
</table>

### 1.8 Geothermal

Geothermal energy comes from the natural heat of the Earth primarily due to the decay of the naturally radioactive isotopes of uranium, thorium and potassium. Because of the internal heat, the Earth’s surface heat flow averages 82 MW/m² which amounts to a total heat of about 42 million megawatts. The total heat content of the Earth is of the order of 12.6 x 10²⁴ MJ, and that of the crust, the order of 5.4 x 10²¹ MJ (Dickson and Fanelli, 2004). This huge number can be compared to the world electricity generation in 2007 of 7.1 x 10¹³ MJ (IEA, 2009). The thermal energy of the Earth is immense, but only a fraction of it can be utilised. So far utilisation of this energy has been limited to areas where geological conditions permit a carrier (water in the liquid or vapour phases) to ‘transfer’ the heat from deep hot zones to or near the surface, thus creating geothermal resources. It is considered possible to produce up to 8.3% of the total world electricity with geothermal resources, supplying 17% of the world
population. Thirty nine countries (located mostly in Africa, Central/South America and the Pacific) can potentially produce 100% of their electricity using geothermal resources.

Table 1.16: Geothermal resource types (White and Williams, 1975)

<table>
<thead>
<tr>
<th>Resource type</th>
<th>Temperature range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convective hydrothermal resources</td>
<td>≈240°</td>
</tr>
<tr>
<td>Vapour dominated</td>
<td>20°-350°</td>
</tr>
<tr>
<td>Hot-water dominated</td>
<td>20°-350°</td>
</tr>
<tr>
<td>Other hydrothermal resources</td>
<td>20°-150°</td>
</tr>
<tr>
<td>Sedimentary basin</td>
<td>20°-150°</td>
</tr>
<tr>
<td>Geopressed</td>
<td>90°-200°</td>
</tr>
<tr>
<td>Radiogenic</td>
<td>30°-150°</td>
</tr>
<tr>
<td>Hot rock resources</td>
<td></td>
</tr>
<tr>
<td>Solidified (hot dry rock)</td>
<td>90°-650°</td>
</tr>
<tr>
<td>Part still molten (magma)</td>
<td>&gt;600°</td>
</tr>
</tbody>
</table>

1.9 Global electricity demand by application

Figure 1.5: Global electricity demand by application (World Energy Council 2013)

Three main sectors which account for approximately 70% of the total electricity consumption in the industrialized countries:

- Motors (40–45%)
- Lighting (15%)
- Home appliances and consumer electronics (15%)

In some developing countries with large industries and outdated electrical equipment, the share of electricity consumed by motors is even higher. Globally electric motors consume about 9000 TWh/year,
but more advanced models could save about 1000TWh and reduce CO2 emissions by 0.8Gt per year. This equals the total annual electricity consumption of a country like Japan.

Ambitious goals for energy efficiency are reaching beyond purely technical solutions to encompass cost-effectiveness, financing, acceptance, innovation and environmental impact assessment. The profitability of investing in energy efficiency technologies is often questioned. Unbiased comprehensive studies of energy efficiency solutions including cost/benefit assessments could help to promote understanding of the potential benefits. Energy efficiency requires a long-term commitment, and the financing framework should take this into account. The loan terms should cover the entire lifetime of the solution.

![World Electricity Consumption by Region](image)

**Figure 1.6:** World electricity consumption by region (World Energy Outlook 2009)

### 1.10 Outlook of energy in the world

The Energy Outlook considers a base case, outlining the 'most likely' path for energy demand by fuel based on assumptions and judgements about future changes in policy, technology and the economy, and develops a number of alternative cases to explore key uncertainties.

In the base case, world GDP more than doubles, but unprecedented gains in energy efficiency mean that the energy required to fuel the higher level of activity grows by only around a third over the Outlook. Fossil fuels remain the dominant form of energy powering the global expansion: providing around 60% of the additional energy and accounting for almost 80% of total energy supplies in 2035. Renewables grow rapidly, almost quadrupling by 2035 and supplying a third of the growth in power generation.
1.11 Outlook of energy in Algeria

In 2011, Algeria adopted a strategy whose objective between now and 2030 was to produce 40% of electricity from renewable resources. This strategy moreover aims to develop a real solar industry associated with a training and capitalization program, which, in time will allow a good knowledge to develop, specifically in the area of engineering and project management. A long-term plan for renewable energy and energy efficiency was adopted with the aim to have in place 22,000MW of capacity between 2011 and 2030, 12,000 MW of which would cover national demand, and 10,000 of which could be exported if there were long-term guarantees of purchase, and if external financing could be secured. This programme includes the building of around sixty photovoltaic solar and thermal solar plants, wind farms and hybrid plants between now and 2020. Its implementation, placed under the aegis of the Ministry of Energy and Mines, is open to public and private operators. Solar power can make up more than 37% of national electricity production between now and 2030. Despite a quite small capacity, the programme does not exclude wind power which makes up the second wave of development and whose share could be around 3% of electricity production by 2030. Algeria also envisages the installation of some units of an experimental size so as to test the different technologies in the area of biomass, geothermal power and desalination of salt water by the different sectors of renewable energy. The first stage of the programme (2011-2013) was mainly devoted to the completion of pilot projects which will test the different technological sectors. The main developments in the area of installed capacity are set out in the following figure.

Figure 1.7: Renewable energy and primary energy forecast (BP Statistical Review 2014)
Conclusion

Presenting the different types of energy, including fossil and renewable sources in national and global levels shows strong effect of environmental, economic and social indicators on energy production. For example, disadvantages of fossil fuel are: high price volatility and high emissions of pollutant gases, such as CO2, but advantages are wide geographic distribution and predictable costs with a leading tradable commodity. In the other side renewable energy have a lot of advantages. It is a clean energy and has a high reliability with a good solution for remote areas. For the disadvantages, it has a high CAPEX, difficulty in transportation and processing implications. Renewable energy stays a flexible in comparison with fossil fuels. After the comparison between the two resources, we could say that using renewable energy like an alternative is a priority for the whole world, especially in this critical time.
Chapter 2: Renewable energy resources and applications in Algeria
Chapter 2: Renewable energy resources and applications in Algeria

Recently, political support for renewable energies has been growing continuously at the national and international level and most scientists now agree that the Middle East and North Africa are perfectly placed to play a leading role in the lucrative future solar and wind power industries. Algeria plays a very important role in world energy markets, both as a significant hydrocarbons producer and exporter, as well as a key participant in the renewable energy market. Due to its geographical location, Algeria has been considered as one of the best countries for exploiting solar energy. Algeria enjoys a relatively high abundance of sunshine, solar radiation, and moderate wind speeds, and biomass and geothermal energy resources.

2.1 Wind Power

Wind is the result of the heating and cooling of the Earth’s surface and atmosphere, leading to convection currents in the air. These currents are present in the volume between the surface of the Earth and the stratosphere, but only a relatively small proportion of the total wind resource is accessible from just above the Earth’s surface, due to both technical and economic reasons.

2.1.1 Configurations

There are two types of wind turbine configuration, horizontal and vertical axis. The horizontal axis wind turbine (HAWT) is the most commonly seen configuration where a vertical tower supports a two or three bladed rotor turning round a horizontal axis (see figure 2.1). The vertical axis wind turbine (VAWT), rotates about a vertical axis by using either vertically mounted blades (known as a Darrieus turbine) which generate lift, or curved scoops (known as a Savonius turbine) which experience more drag as they move with the flow of wind, compared to when they are moving against the direction of wind flow. A variation on the vertical bladed system using blades which wrap round the vertical axis in a helical fashion is called a Gorlov turbine (see figure 2.2).

Figure 2.1: Horizontal axis wind turbines (google images)
HAWTs have proved to be the default format for commercially available systems, while VAWTs, although capable at smaller scales, have not yet been shown to be durable enough when scaled up, in the case of the Darrieus systems (blade breakages), or efficient enough in the case of the Savonius device. On this basis, the next section of work will focus only on HAWTs and their design. Although wind turbines can outwardly appear to be very similar, there are many variations across both manufacturers and turbine size scales. At the top of a wind turbine tower sits a nacelle which houses many of the sub-systems required to convert wind power into electricity. At the front of the nacelle is the rotor assembly, comprising a hub and usually three blades constructed from composite material.

On larger machines, the blades are pitch adjustable to allow the amount of force transferred from the wind to be varied, in order to control the speed at which the rotor turns. Pitching the blades out of the wind completely will slow the rotor and it will eventually stop turning. Controlling the direction the rotor faces on a large wind turbine is a wind vane, normally positioned on top of the nacelle. As it turns, the wind vanes movement is detected by a control system which activates a yaw mechanism rotating the entire nacelle around the vertical axis of the tower on a large main bearing, thus ensuring that the rotor is always facing into the wind. Also found on top of the nacelle is an anemometer linked to a second control system which adjusts the pitch of the rotor blades according to the wind speed measured by the anemometer (see figure 2.3).
The generator is commonly an asynchronous machine and is directly connected to the electricity grid. This is made possible because a gearbox increases the rotor speed of 5-20 rpm up to about 750-3600 rpm at the generator. Direct drive systems use gearless permanent magnet synchronous generators which operate at much lower rotational speeds. The main benefits in comparison to an asynchronous machine include lower levels of mechanical wear from the lower rotational speed, and less machine stress, as there is a higher degree of speed variability. This variability in speed also means that the electrical output must be converted to DC and then back to AC before reaching the electricity grid, as the voltage and frequency are a function of the speed of rotation of the generator.

During operation, generators produce high levels of heat and therefore require continuous cooling. This can be achieved by incorporating air ducts which channel air around the generator, or by using a water cooling system which requires a radiator to be placed outside of the nacelle for transferring the heat from the cooling water to the outside air.

2.1.2 Wind energy in Algeria

The wind resource has also been assessed by the developer, Sonelgaz, and at present, there are six pilot projects for electrification and telecommunication which are identified and quantified. These are Adrar, Tindouf, BordjBadji Mokhtar, Bechar, Tamanrassat and Djanet.
Table 2.1: The annual average wind velocities in six identified places (Himri Y et al., 2010)

<table>
<thead>
<tr>
<th>Sites</th>
<th>Adrar</th>
<th>Tindouf</th>
<th>Bechar</th>
<th>Tamanrassat</th>
<th>Ouargla</th>
<th>djanet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual average speed (m/s)</td>
<td>6.3</td>
<td>5.1</td>
<td>4.4</td>
<td>3.7</td>
<td>3.5</td>
<td>3.3</td>
</tr>
</tbody>
</table>

The region of Adrar receives the most wind in the country judging from the results of the preliminary survey. The evaluations of powers recoverable at heights of 10 to 50 m could conclude in registering this region as a favourable site for the establishment of a windy farm. Other sites (North, High Plateaux) hide non-negligible energetic potentials. The installation, by Sonelgaz, of a 30 MW wind farm in Adrar region and the nine assessment stations in different regions of Algeria is seen as a second step in stimulating much faster the use of the wind power. The topography and terrain roughness of these prospective wind sites are also measured and quantified to better simulate and understand the wind flow.

2.1.3 Algerian wind power projects

The wind farms that was developed between 2011 and 2015 to be used as pilot:

- 2010-2013 the installation of 10MW
- 2014-2015 the installation of 40MW

During the period 2016-2030 a capacity of 1700MW of wind power will be installed (Renewable Energy and Energy Efficiency Program 2011)

2.2 Solar Power

Solar is the highest power that can be used by human in the earth. It can be exploited in two ways; as a thermal source in heating, hot water, etc and as an electricity source such as, a photovoltaic (PV) technology and concentrating solar power (CSP).

![Figure 2.5: Solar power park](image)

Two methods currently exist for generating electricity from sunlight; a direct conversion process using PV technology and an indirect conversion process called CSP, where focussed sunlight heats a fluid for use in a heat engine connected to a generator. While PV devices can be employed at all scales of power
generation almost anywhere in the world, CSP is particularly suited to larger scale projects in regions with the greatest natural sun resource.

### 2.2.1 Solar PV

The following sections will expand upon the use of PV technology:

![Single PV panel (google image)](image)

**Figure 2.6**: Single PV panel (google image)

The two most prevalent systems employed in PV devices are flat plate systems and concentrator systems. With flat plate systems, the PV cells are constructed on a flat, rigid surface whereas concentrator systems use lenses to focus sunlight on to PV cells to increase the power output. Both systems are packaged into panels with multiple panels being connected in series or parallel to form arrays. PV technology enables the direct conversion of sunlight into electricity through the photovoltaic effect, where a photon of light striking an electron in a PV device becomes liberated and can flow into an external circuit, giving rise to an electric current. The efficiency of this process is dependent on a variety of factors but the materials used and construction methods are of primary importance.

Inside an atom, electrons form valance bonds with neighbouring atoms and are not free to move about. This is known as the stable state or valence band. If a photon of sufficient energy is incident upon one of these stable state electrons it absorbs the energy and leaves the valence band for a higher energy level in the conduction band, where the electron is now mobile and capable of conduction. The space left by the electron in the stable band is now occupied by a “hole”, effectively a charge equal in size but opposite in polarity to that of an electron. If large numbers of electrons move to the conduction band, a current flow will result (a flow of electrons and holes). The amount of energy required to raise an electron from the stable state to the conduction band is called the band gap energy and is specific to different materials. If the incident photon possesses less than the band gap energy it will not be absorbed and the electron will remain in the valence band. This means that light above a certain wave length is not useful, possessing insufficient energy to effect this transition, according to the Planck-Einstein equation:
\[ E = \frac{h c}{\lambda} \] (2.1)

Where,
E = energy in J
h = Planck’s constant: \(6.626 \times 10^{-34}\) Js
\(c\) = speed of light: \(3 \times 10^8\) m/s
\(\lambda\) = wave length in m

However, if an incident photon has more energy than the band gap the electron will still only move with the band gap energy to the conduction band while the excess is released as heat, effectively wasted energy. So the efficiency of energy conversion from a photon to an electron decreases as the photon energy increases beyond the band gap energy. These criteria of wavelength usefulness and conversion efficiency place a fundamental limitation on the overall efficiency a PV device can deliver. Realising this conversion of sunlight into electricity requires a p-n junction to be formed using a semiconductor material which is doped both as n-type, meaning an excess of electrons, and p-type, a deficiency of electrons. Having regions of p and n-type material neighbouring each other creates a p-n junction where a reverse electric field exists, promoting electron flow across the junction from p-type to n-type when an external load is attached to both p and n-type sides.

**Figure 2.7:** Schematic of typical PV panel (google image)

There are a large number of materials which can be used to construct PV panels and each material has a special efficiency and a typical application as it is shown in table 2.2.
Table 2.2: Summary of PV materials (Mah O, 1998)

<table>
<thead>
<tr>
<th>Material</th>
<th>Structure</th>
<th>Manufacturing Cost</th>
<th>Efficiency</th>
<th>Typical Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>Single crystal</td>
<td>High</td>
<td>15-20%</td>
<td>Flat plate</td>
</tr>
<tr>
<td>Si</td>
<td>Polycrystaline</td>
<td>Medium</td>
<td>10-14%</td>
<td>Flat plate</td>
</tr>
<tr>
<td>Si</td>
<td>Compound crystalline</td>
<td>High</td>
<td>25-30%</td>
<td>Concentrating</td>
</tr>
<tr>
<td>a-Si</td>
<td>Thin film</td>
<td>Low</td>
<td>5-10%</td>
<td>Flat plate/surface covering</td>
</tr>
<tr>
<td>CdTe</td>
<td>Thin film</td>
<td>Low</td>
<td>5-10%</td>
<td>Flat plate/surface covering</td>
</tr>
<tr>
<td>CulnSe2</td>
<td>Thin film</td>
<td>High</td>
<td>15-20%</td>
<td>Flat plate/surface covering</td>
</tr>
</tbody>
</table>

2.2.2 Solar thermal

Solar thermal energy is a technology that converts solar radiation into thermal energy. It can be used directly (for example to heat buildings) or indirectly (to produce steam to power turbo alternators that generate electric power). Direct solar radiation is concentrated by a collector on an absorber where it is transferred into a fluid that is either sprayed directly or drives the heat to a steam generator. All solar energy systems have a number of elements in common: a collector that concentrates the heat, a liquid or gas that transfers the heat to an extraction point, an evaporator, a turbine and a generator.

Solar thermal power plants produce electricity in much the same way as conventional power stations. Four main elements are required: a concentrator, a receiver, some form of heat transport media or storage, and power conversion. Many different types of systems are possible, including combinations with other renewable and non-renewable technologies, but the three most promising solar thermal technologies are:

a- Parabolic Trough

Parabolic trough-shaped mirror reflectors are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough focal line. In these tubes a thermal transfer fluid is circulated, such as synthetic thermal oil. Heated to approximately 400°C by the concentrated sun’s rays, this oil is then pumped through a series of heat exchangers to produce superheated steam. The steam is converted to electrical energy in a conventional steam turbine generator, which can either be part of a conventional steam cycle or integrated into a combined steam and gas turbine cycle.
b-Central Receiver (Solar Tower)

A circular array of heliostats (large individually-tracking mirrors) is used to concentrate sunlight on to a central receiver mounted at the top of a tower. A heat transfer medium in this central receiver absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy to be used for the subsequent generation of super heated steam for turbine operation. Heat transfer media so far demonstrated include water/steam, molten salts, liquid sodium and air. If a gas or even air is pressurised in the receiver, it can be used alternatively to drive a gas turbine (instead of producing steam for a steam turbine).

c-Parabolic Dish

A parabolic dish-shaped reflector is used to concentrate sunlight on to a receiver located at the focal point of the dish. This absorbs energy reflected by the concentrators, enabling fluid in the receiver to be heated to approximately 750°C. This is then used to generate electricity in a small engine, for instance Stirling engine or a micro turbine, attached to the receiver.
2.2.3 Solar energy in Algeria

The history of using solar energy in Algeria backs to 1954 with the solar furnace built by the French for ceramic fabrication purpose. The insulation time over the quasi-totality of the national territory exceeds 2000 hours annually and may reach 3900 hours (high plains and Sahara). The daily obtained energy on a horizontal surface of 1m² is of 5 KWh over the major part of the national territory, or about 1700 KWh/m²/year for the North and 2263 KWh/m²/year for the South of the country.

![Figure 2.10: Parabolic Dish (solar thermal power 2010)](image)

![Figure 2.11: Map of Algeria annual solar irradiance potential](image)

Table 2.3: Solar potential in Algeria (CDER 2008)

<table>
<thead>
<tr>
<th>Areas</th>
<th>Coastal area</th>
<th>High plateau</th>
<th>Sahara</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface (%)</td>
<td>4</td>
<td>10</td>
<td>86</td>
</tr>
<tr>
<td>Average duration of sunning(Hours/Year)</td>
<td>2650</td>
<td>3000</td>
<td>3500</td>
</tr>
<tr>
<td>Received average energy(kWh/m²/year)</td>
<td>1700</td>
<td>1900</td>
<td>2650</td>
</tr>
</tbody>
</table>
2.4 Algerian solar power projects

Algeria seeks to develop its solar potential, which is one of the most important in the world, by launching major projects in solar thermal. Pilot projects for the construction of two solar power plants with storage of a total capacity of about 150 MW each, were launched during the 2011-2013 period. These are in addition to the hybrid power plant project of Hassi R’Mel with a total power capacity of 150 MW.

Four solar thermal power plants with a total capacity of about 1 200 MW are to be constructed over the period 2016-2020. The 2020-2030 programme provides for the installation of an annual capacity of 500 MW until 2023, then 600 MW per year until 2030 (Renewable Energy and Energy Efficiency Program).

2.3 Hydro Power

The movement of water down rivers and from lakes gives rise to hydro power, or when electricity is produced, hydroelectric power. At a higher vertical position, water possesses stored potential energy but as it flows to a lower vertical position under the influence of gravity, the fluid gains kinetic energy. A turbine can be used to extract energy from this downwards flow, converting it to mechanical energy and if a generator is connected, into electrical energy.

![Figure 2.12: hydro power (google image)](image)

2.3.1 Configurations

In general, there are three types of hydro scheme: storage, run of-river, and diversion. All of them share the main components of; an intake, penstock (pipe from the intake to the turbine), powerhouse containing a turbine, tailrace (the channel which returns water having passed through the turbine back to the river or lake) and an electrical substation for connecting the generated electricity to the local network.

In a storage configuration, water is amassed upstream of the power house using either an existing lake, or by construction of a dam to create a reservoir. This enables the flow of water downstream to be controlled. Storage schemes will often have a sufficient volume of water to overcome seasonal fluctuations in water flow to provide a consistent supply of electricity throughout the year. A variation of this layout, where the water is also stored in another reservoir after passing through the turbine so it can be pumped back up to the top reservoir, is called pumped storage. Periods of low energy demand (off-
peak hours), such as during the night, can be used to pump water to the upper reservoir so it can be reused during periods of high energy demand (peak hours).

With a run-of-the-river configuration, a dam or weir is constructed across a river, not to stop the flow of the river, but to divert some of the flow into an intake and to a turbine. As it is the flow of the river that is being used, there is little storage available, so power output can be greatly affected by seasonal fluctuations in weather.

![Run-of-the-river scheme (google image)](image)

**Figure 2.13:** Run-of-the-river scheme (google image)

When water is diverted away from its river or stream source and towards a turbine, it is known as a diversion or canal system. A dam or weir is used to divert some of the flow either along an open channel or through a penstock towards the turbine location.

![Diversion Scheme (Practical Action, 2010)](image)

**Figure 2.14:** Diversion Scheme (Practical Action, 2010)

Since different hydroelectric sites possess particular properties, a variety of hydro turbine technology has been developed to reflect this so that the converted energy can always be extracted in the most efficient manner. As water can be sourced from mountainous regions or low lying rivers, the amount of head can vary significantly, as can the flow rates experienced.

A hydro turbine converts the movement of flowing water into the mechanical rotation of a shaft. Choosing the turbine best suited to a particular site will strongly depend upon the key characteristics of
head and flow for the site. Other parameters that should be considered are the generator running speed and whether the turbine is required to be producing power when only part flow conditions are applicable. Turbines can be grouped as either reaction turbines (suited to lower head applications) or impulse turbines (higher heads). The middle ground, medium heads, accommodates both classes of turbine with other factors, such as flow, required to determine which is best suited for a specific site. In a reaction turbine, power is produced both from velocity and pressure forces so large surfaces are required for these forces to act on. Their defining characteristic relies on the casing containing the runner being completely filled with water in order for it to function. To achieve optimum performance, the direction of water flow on entering the turbine is important. Three types of reaction turbine exist: Francis, propeller, and Kaplan.

![Francis Turbine](image)

**Figure 2.15: Francis turbine (google images)**

A Francis turbine is comprised of a wheel, or runner, constructed with fixed blades sandwiched between two rims, surrounded by a circle of adjustable guide vanes used to control the amount of water reaching the runner and causing it to spin.

The vanes are enclosed by a spiral casing, which carries the supply water to them. After passing through the runner from the side, the water exits the centre of the runner and down a draft tube to the tail-race. Also classed as radial flow reaction turbines, Francis turbines are generally designed specifically to meet the needs of the intended installation. The complexity of the vane system, together with the design specialisation, makes Francis turbines less suited to smaller scale hydro projects due to the design and development costs involved, despite the high efficiency of the end product.

When only a small head of water is available, a propeller turbine, which resembles a ship’s propeller, is frequently suitable the propeller is located within the penstock with the turbine shaft exiting the pipe where a change in direction occurs. Upstream of the propeller is a set of fixed blades or swivel gates, also known as wicket gates, to control the flow of water. As the pitch angle of the blades is fixed, this device is also known as a fixed blade axial flow turbine. The efficiency of such a system is seriously compromised if the penstock is not full of water (part-flow) at the turbine due to the fixed pitch angle of the blades, but some allow blade pitch to be changed to match the flow of water.
More sophisticated propeller turbine devices are used at large scale hydro installations where to achieve the best efficiency, not just blade pitch and wicket gate adjustments are possible, but the flow of water is conditioned with some swirl before reaching the turbine runner. Swirl, is absorbed by the runner, so that a straight flow is returned to the draft tube. Mounting a set of guide vanes upstream of the runner can induce the desired swirl or snail’s shell housing, as in a Francis turbine, where water is forced to spiral as it exits the snail shell tangentially. This type of turbines is known as a Kaplan or variable pitch turbine. As with other propeller turbines, a Kaplan is quite versatile during installation as it can be positioned vertically, horizontally or at any angle.

Unlike a reaction turbine which operates best when fully immersed in water, an impulse turbine operates in air while extracting power from jets of water striking an arrangement of blades or cups around a wheel, causing the wheel to turn. The three common types of impulse turbine are the Pelton, Turgot, and Cross flow.

Being probably the best known tangential flow impulse turbine, the Pelton wheel operates efficiently over a wide range of flow rates but is particularly suited to low flow situations with larger heads. With cups or buckets placed round the outer edge of the rim, the Pelton wheel bears a striking resemblance to the wheels found at water mills of yesteryear. At the end of the penstock are one or more nozzles, which direct a jet or jets of water at high speed into the buckets, causing the wheel to rotate. The buckets are profiled into left and right halves to smoothly deflect water away from the incoming jet, thus preventing
their central area from being a dead spot. The notch at the outer edge of each bucket allows the water jet to propel a leading bucket for a longer period before the following bucket cuts off the jet. It also serves to provide a smoother entrance to the jet for the bucket.

**Fig. 2.18:** Pelton wheels (Tooling & Production, 2008)

Having multiple jets allows a smaller wheel to be used and this increases the rotational speed for a given flow. If flow reduces, good part-flow efficiency can be achieved by reducing the number of jets being used with the remaining jets still receiving an optimum flow. It is also possible to have two Pelton wheels mounted on the same shaft, instead of a large single wheel, to achieve faster rotation or to accommodate a large number of water jet nozzles.

The Crossflow turbine is also known as either a Banki Crossflow turbine or a Mitchell Crossflow turbine after its inventors who developed the turbine independently in a similar time period. It is comprised of a cylindrical runner made up of blades, and rotates about a horizontal axis. The incoming flow of water is shaped into a sheet along the length of the runner and directed tangentially to the blades at the top of the runner about halfway across its diameter.

The water exerts a force on the blades as it passes through them at the top before crossing the empty central part of the runner and re-entering the blades, now at the bottom of the runner, exerting a further force on the blades before finally exiting. This double pass for the water through the blades in both directions makes the turbine self-cleaning, as particulates deposited on a blade surface during the first pass are cleaned away again during the second pass. The cylindrical nature of the runner allows the turbine to run as a multi-cell unit using only part of the runner with low flows, but expanding to use the full length of the runner for higher flows.
2.3.2 Hydro power in Algeria

The overall flows falling over the Algerian territory are important and estimated to 65 billions m³, but of little benefit to the country: restrained rainfall days, concentration on limited areas, high evaporation and quick evacuation to the sea. Schematically, the surface resources decrease from the North to the South. Currently the evaluation of useful and renewable energies is about 25 billion m³, of which the 2/3 approximately is for the surface resources. 103 dam sites have been recorded. More than 50 dams are currently operational. The share of these small-sized production parks is about 5% which supplements the natural gas production of electricity. The total capacity of 13 of them is 269.208 MW as shown in table 2.3. Hydraulic electricity represented, with 265 GWh, barely 1% of the total electricity production. The electricity generation from hydropower is low due to the fact that the precipitation is low and unevenly distributed throughout the country.

Table 2.4: Algerian hydroelectric production park (mem-algeria)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Installed power (MW)</th>
<th>Plant</th>
<th>Installed power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darguina</td>
<td>71.5</td>
<td>Ighzernchebel</td>
<td>2.712</td>
</tr>
<tr>
<td>IghilEmda</td>
<td>24</td>
<td>Gouriet</td>
<td>6.425</td>
</tr>
<tr>
<td>Mansouria</td>
<td>100</td>
<td>Bouhanifia</td>
<td>5.700</td>
</tr>
<tr>
<td>Erraguene</td>
<td>16</td>
<td>Oued Fodda</td>
<td>15.600</td>
</tr>
<tr>
<td>Souk El Djemaa</td>
<td>8.085</td>
<td>Beni Behde</td>
<td>3.500</td>
</tr>
<tr>
<td>TiziMeden</td>
<td>4.458</td>
<td>Tessala</td>
<td>4.228</td>
</tr>
<tr>
<td>Ghrib</td>
<td>7.000</td>
<td>Total</td>
<td><strong>269.208</strong></td>
</tr>
</tbody>
</table>
2.4 Biomass Power

Biomass is a general term for living, or recently living, biological matter in most forms whether solid, like wood; liquid, like bio-ethanol; or gas, like methane. Not included are fossil fuels, as these organic materials have been absent from the carbon cycle for thousands of years, while geological processes have been forming them. Most commonly used as a fuel for heating or generating electricity, biomass, whether in its raw or processed state, ultimately undergoes combustion to release its embedded energy. Unlike other renewable sources which are free to be harvested e.g. wind, solar, etc. biomass is a fuel and more often than not it will have to be purchased. The amount of biomass material available around the world is extensive, although much of this can be counted as food or required for other uses such as building materials. For biomass to be viable over the longer term, it also has to be controlled sustainably with continued replanting otherwise fuel shortages can occur - not a desirable situation, especially for an operator whose revenue stream relies on the sale of a continuous flow of electricity generated from biomass.

2.4.1 Configurations

Composed of a mixture of organic molecules, primarily made up from carbon and hydrogen atoms, the structure of biomass often includes oxygen, nitrogen and sometimes alkali, alkaline earth, and heavy metals. The main sources of biomass are wood, crops, and waste. Although not currently a main source of biomass, algae is attracting much research interest as it composition seems suited to the production of liquid fuels. Transforming biomass to more useful fuels is achieved either through thermal or biochemical conversion.

Wood can be incinerated directly in large pieces or chipped to make smaller ones. Sawdust and waste wood can be reformed into pellets, pucks and logs to form a material of greater density more suitable for transportation and feeding thermal generation systems. Although primarily used for space and water heating on both residential and commercial scales or for co-firing fossil fuelled systems, it is also possible to raise steam for powering an engine, which when linked to a generator, produces electricity. This can be the basis for a combined heat and power (CHP) scheme serving communities and businesses.

Pulping liquor, sometimes called black liquor, is a by-product of the chemical breakdown of wood in the pulping and paper industries and is a major source of energy from wood. In fact many pulp mills have recovery boilers where the black liquor is burned, generating steam and recovering chemicals, both of which are re-used in the process. This greatly reduces reliance on other energy sources while also reducing waste products.

Crops, whether originally grown for food, or energy crops specifically grown for their energy content, can be incinerated but are usually more suited to the production of a variety of liquid fuels. Although
particularly appropriate in the transportation sector, liquid bio-fuels also have a role to play in remote locations off grid, where engines are used to generate electricity or function as back-up systems.

Biologically produced alcohols, such as bio-ethanol, can be made from the fermentation of plant materials containing sugar, typically from sugar or starch crops such as wheat, sugar beet, sugar cane, and corn. Although it can be used as a fuel source for internal combustion engines in its own right, bioethanol is widely used as a petrol additive in some countries to increase octane level and reduce emissions.

Two forms of diesel can be extracted from crops possessing high oil content such as rape seed, jatropha, soy, and sunflower. Green diesel is produced when the extracted plant oils undergo the same fractional distillation process used for fossil fuel oil separation. This results in green diesel being a very similar product to fossil fuel sourced, or mineral, diesel and it can become busted in a standard diesel engine without modification.

Biodiesel comes from plant oils or animal fats which experience transesterification, resulting in a product similar in composition to petroleum diesel but with some stark differences. It is readily biodegradable, has low toxicity, and a much higher flashpoint. 100% pure biodiesel (B100) can be used in conventional diesel engines, however more modern common rail systems can only operate correctly with biodiesel if it is blended first with mineral diesel collected and combusted, where the resultant carbon dioxide and water are also less harmful forms of GHG.

A controlled version of anaerobic digestion can also take place in a closed tank, or anaerobic digester (Figure 2.20), where the biomass feedstock is broken down as described previously, but the resultant biogas is collected and used to feed a gas engine, usually part of a CHP system, where it is combusted. At smaller scales, the heat captured in the CHP system can be reused to help sustain the digestion process while the electricity generated is exported and sold to the grid. With larger systems, the amount of heat captured may also be sufficient for a district heating scheme to be implemented.

Figure 2.20: Anaerobic digestion system for electricity generation
If the digester is exclusively fed energy crop material such as silage it will result in the dedicated production of biogas. In Europe, these are known as biogas plants, while an agricultural anaerobic digester that accepts two or more feedstock types for simultaneous digestion are called co-digestion or co-fermentation plants. The leftover solid organic material from the anaerobic digestion process is rich in nutrients and it can be distributed back on to the land as an effective fertilizer.

2.4.2 Biomass energy in Algeria

Biomass potential is relatively limited. In general, Algeria is divided into two parts. The wooded areas cover about 250 million hectares or a little more than 10% of the total area of the country. The Saharan areas cover almost 90% of the territory. In the north of Algeria, forests cover 1.8 million hectares and scrub around 1.9 million hectares. The total theoretical biomass potential is estimated at 37 Mtoe, of which about 10% may be recoverable. Some 5 million tons of urban and agricultural waste are produced each year. The theoretical energy potential is about 1.33 Mtoe/year.

2.5 Geothermal energy

Geothermal energy is the energy derived from the heat of the earth's core. It is clean, abundant, and reliable. If properly developed, it can offer a renewable and sustainable energy source. People have used geothermal resources in many ways, including healing and physical therapy, cooking, space heating, and other applications. One of the first known human uses of geothermal resources was more than 10,000 years ago with the settlement of Paleo-Indians at hot springs. Geothermal resources have since then been developed for many applications such as production of electricity, direct use of heat, geothermal heat pumps.

2.5.1 Configurations

a. Electric power generation

Geothermal power is generated by using steam or a hydrocarbon vapour to turn a turbine-generator set to produce electricity. A vapour-dominated (dry steam) resource can be used directly, whereas a hot-water resource needs to be flashed by reducing the pressure to produce steam, normally in the 15-20% range. Some plants use double and triple flash to improve the efficiency, however in the case of triple flash it maybe more efficient to use a bottoming cycle (a small binary plant using the waste water from the main plant). Low-temperature resources generally require the use of a secondary low boiling-point fluid (hydrocarbon) to generate the vapour, in a binary or Organic Rankine Cycle (ORC) plant.

Usually a wet or dry cooling to where is used to condense the vapour a fter it leaves the turbine to maximise the temperature and pressure drop between the incoming and outgoing vapour and thus increase the efficiency of the operation. However, dry cooling is often used in arid areas.
Binary plant technology is playing a very important role in the modern geothermal electricity market. The economics of electricity production are influenced by the drilling costs and resource development (a typical capital expenditure or Capex quota is 30% for reservoir and 70% plant). The electricity productivity per well is a function of reservoir fluid thermodynamic characteristics (phase and temperature). The higher the energy content of the reservoir fluid, the lesser the number of required wells and as a consequence the reservoir Capex quota is reduced.

Single geothermal wells can produce from 1–5 MWe, however, some producing as high as 30 MWe have been reported. Binary plants on the reinjection stream could be a very effective way of producing cheap energy, because there would not be any additional pumping costs.

b- Direct utilisation

The main advantage of using geothermal energy for direct use projects in the low- to inter-mediate-temperature range is that such resources are more widespread and exist in at least 80 countries at economic drilling depths. In addition, there are no conversion efficiency losses and projects can use conventional water-well drilling and off-the-shelf heating and cooling equipment (allowing for the temperature and chemistry of the fluid). Most projects can be on line in less than a year. Projects can be on a small scale, such as for an individual home, greenhouse or aquaculture pond, but can also be a large-scale commercial operation such as for district heating/cooling, or food and lumber drying.

It is often necessary to isolate the geothermal fluid from the user side to prevent corrosion and scaling. Care must be taken to prevent oxygen from entering the system (geothermal water is normally oxygen-free), and dissolved gases and minerals such as boron and arsenic must be removed or isolated, as they are harmful to plants and animals. Hydrogen sulphide, even in low concentrations, will cause problems with copper and solder and is harmful to humans. On the other hand carbon dioxide, which often occurs in geothermal water, can be extracted and used for carbonated beverages or to enhance growth in greenhouses. The typical equipment for a direct-use system includes down hole and circulation pumps, heat exchangers (normally the plate type), transmission and distribution lines (normally insulated pipes), heat extraction equipment, peaking or back-up plants (usually fossil-fuel fired) to reduce the number of geothermal wells required, and fluid disposal systems (injection wells). Geothermal energy can usually meet 80–90% of the annual heating or cooling demand, yet only be sized for 50% of the peak load.

c- Geothermal heat pumps

Ground-source heat pumps (GHPs) use the relatively constant temperature of the earth to provide heating, cooling and domestic hot water for homes, schools, governmental and commercial buildings. A small amount of electricity input is required to run a compressor, however the energy output is in the order of four times this input. The technology is not new: Lord Kelvin developed the concept in 1852, which was then modified as a GHP by Robert Webber in Indianapolis in 1945. GHPs gained commercial recognition
in the 1960s and 1970s. Europe began using this technology around 1970 and it now popular in the USA, Canada, Germany, Sweden, Switzerland, France and other western European countries.

GHPs come in two basic configurations: ground-coupled (closed loop) which are installed either horizontally or vertically, and groundwater (open loop) systems, which are installed in wells and lakes. The type chosen depends upon the soil and rock type at the installation, the operation of a typical geothermal heat pump in either heating or cooling mode. A desuper heater can be provided to use reject heat in the summer and some input heat in the winter for domestic hot water heating. input heat in the winter for domestic hot water heating.

![Figure 2.21: GHPS](image)

### 2.5.2 Geothermal energy in Algeria

There are more than 240 thermal springs in Algeria. Three geothermal zones have been delineated according to some geological and thermal considerations: (1) The Tlemcenian dolomites in the north western part of Algeria, (2) carbonate formations in the north eastern part of Algeria and (3) the sandstone Albian reservoir in the Sahara (south of Algeria).

Three geothermal regions have been delineated according to the distribution of thermal springs and geological and geophysical considerations (such as permeability and geothermal gradient) presented in Figure 2.21. The inventory of the thermal springs has been updated to show more than 240 sites. The temperatures of Algerian hot waters vary from 22 to 98°C. The highest spring temperatures recorded are: 68°C for the western area (Hammam Bouhnifia), 80°C for the central area (Hammam El Biban) and 98°C for the eastern area (Hammam Meskhoutine) in northern Algeria. In the southern area, there are some thermal springs with a mean temperature of 50°C. The total dissolved solids (TDS) of the hot springs in northern Algeria are greater than 1 g/L. Carbonate formations constitute the main geothermal reservoirs in northern Algeria, while in southern Algeria the reservoirs are dominantly composed of sandstone.
2.6 The assessed renewable technologies in south of Algeria

After presenting the main renewable energy technologies and their resources, which have variable potentials in the world and Algeria, five different types of renewable energy were chosen to be studied. This choice has been based on the renewable energy resource in the south of Algeria:

1. Solar thermal
2. Solar PV
3. Geothermal
4. Wind
5. Biomass

In addition to 10 combination between the renewable technologies which are:

\[ N = \frac{n(n-1)}{2} = 5 \times 4 / 2 = 10 \]

where; \( n \) number of single technologies and \( N \) number of hybrids

1. Hybrid: Solar thermal / Solar PV
2. Hybrid: Solar thermal / Wind
3. Hybrid: Solar thermal / Geothermal
4. Hybrid: Solar thermal / Biomass
5. Hybrid: Solar thermal/Wind
6. Hybrid: Solar PV /Geothermal
7. Hybrid: Solar PV /Biomass
8. Hybrid: Geothermal /Wind
9. Hybrid: Geothermal/ Biomass
10. Hybrid: Wind/ Biomass

Lately in chapter 4, we will discuss the possibility of eliminating any of these renewable technologies based on its suitability with the case of study.

Figure 2.22: Main Algerian geothermal areas (H.Saibi;2015)
**Thesis problematic**

When we compare between this technologies renewable energy projects, using some criteria at this table below:

<table>
<thead>
<tr>
<th>Table 2.5: Example of performance matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Efficiency (%)</strong></td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Land use (m^2/MWh)</strong></td>
</tr>
<tr>
<td><strong>Cost ($/MW)</strong></td>
</tr>
<tr>
<td><strong>Job creation (job-years/GWh)</strong></td>
</tr>
</tbody>
</table>

If we would like to compare between these technologies and take biomass and wind as an example of comparison, we obtain these results:

Wind energy is better than biomass in efficiency (100> 35) and land use (1.75<12.75) however, it is worse in cost (76.28>72) and job creation (0.17<0.21). At this point, a clear choice cannot be made easily, so using multi criteria decision analyses MCDA methods is a recommended solution.

**Conclusion**

Algeria has large reserves of energy sources, mainly solar energy. Regarding the completed assessment of all types of the renewable, it appears that there is a considerable potential for the utilization of renewable energy sources especially with respect to solar, geothermal and wind power. However the level of development of such energy sources is rather primary, but efforts should increase because of the ever growing concern about the environment friendly sources of energy. It is now important in educating the public as well as introducing special energy legislation to increase the usage of this clean form of energy whether in private or public sectors and show the importance of energy efficiency and conservation.

We have found a difficulty in the initial selection of appropriate renewable energy technologies to be assessed due to the high number of the hybrids that can be combined. In this study, all the combinations of two renewable energy technologies were chosen. The next chapter will contain multi-criteria decision analysis methods to solve this problem.
Chapter 3: Multi-Criteria Decision Analysis (MCDA) Methods
Chapter 3: Multi-Criteria Decision Analysis (MCDA) Methods

As it was mentioned previously in chapter 2, selecting the best alternative from a number of different renewable technologies is a very difficult stuff due to the diversity of the indicators (criteria) that are used to assess the technologies or alternatives. The complex interactions shown in figure 3.1 make decision making (DM) extremely complicated.

Figure 3.1: The complex interactions of energy system (Wang et al, 2009)

Sustainable development means the satisfaction of present needs without compromising the ability of future generations to meet their own needs (WCED, 2009). Sustainability can be seen as the final goal: a balance of social and economic activities and the environment (Hofman K, 2009). A sustainable energy sector has a balance of energy production and consumption and has no, or minimal, negative impact on the environment (within the environmental tolerance limits), but gives the opportunity for a country to employ its social and economic activities. The rational decision-making (DM) in energy supply system options, planning, management and economy is helpful to the sustainable development.

3.1 Criteria selection

Developing evaluation criteria and methods that reliably measure sustainability is a prerequisite for selecting the best alternative, identifying non-sustainable energy supply system, informing design-makers of the integrated performances of the alternatives and monitoring impacts on the social environment. The development and selection of criteria require parameters related to the reliability, appropriateness, practicality and limitations of measurement. The used criteria to evaluate the energy supply systems in the literatures mainly divide to four aspects: technical, economic, environmental and social criteria.
3.1.1 Technical criteria

a - Efficiency

Efficiency refers to how much useful energy we can get from an energy source. The efficiency coefficient is the ratio of the output energy to the input energy, which is used to evaluate energy systems. It has been proved that efficiency improvement that is consistent with high plant reliability and low-cost of products is economically beneficial (Beer JM. 2007). Efficient energy use is essential to slowing the energy demand growth. It is the most used technical criteria to evaluate energy systems.

b - Safety

Continuous changes in technology, environmental regulation and public safety concerns make the analysis of complex safety-critical of energy systems more and more demanding. Safety of energy systems is vital to society, national development and people’s life. The basic safety of workers on the site of energy project is guaranteed first. Safety is often seen as one of a group of related disciplines: quality, reliability, availability, maintainability and safety. The criteria are specifically defined when sustainable energy DM. Safety can be a technical evaluation criteria of applied technology and also a social criteria to show their effects of energy systems to society and people, etc. (wang et al 2009).

3.1.2 Economic criteria

a - Investment cost

Investment cost comprises of all costs relating to: the purchase of mechanical equipment, technological installations, construction of roads and connections to the national grid, engineering services, drilling and other incidental construction work. Labor costs or costs for the equipment maintenance are not included in investment costs. Nuclear and coal-fired units are characterized by high investment costs and low operating costs while gas-fired generation is characterized by lower capital costs and higher operating costs. The investors must consider the investment costs and the benefit. Investment cost is the most used economic criteria to evaluate energy systems.

b - Operation and maintenance cost

Operation and maintenance costs consist of two parts. One is the operation cost that includes employees’ wages, and the funds spent for the energy, the products and services for the energy system operation. Another is the maintenance cost that aims to prolong energy system life and avoid failures that may lead to its operation suspension.
3.1.3 Environmental criteria

a- CO2 emission

CO2 is a colorless, odorless and tasteless gas that is about one and a half times as dense as air under ordinary conditions of temperature and pressure. It was reported that CO2 contributes 9–26% to the greenhouse effect (Kiehl JT, 1997). CO2 is mainly released through the combustion of coal/lignite, oil and natural gas in energy systems. The disafforestation in the world lessens the removal of atmospheric CO2 by photosynthesis and also contributes to the greenhouse effect. Different energy systems have different CO2 emissions. For example, new technology combining cycles burning natural gas can save practically 33% of CO2 emissions with regard to conventional cycles. CO2 leads to the global warming, which is focused by many governments, academies, and researchers. Naturally, CO2 emission of energy system is certainly a criteria to evaluate its sustainability (Wang et al, 2009).

b- Land use

Energy system occupies some land. The land required by each plant is a matter of great concern for their evaluation (Wang et al, 2009). The environment and landscape are affected directly by the land occupied by energy systems. Land use can also be a social criteria to evaluate the energy system. It represents one of the most critical factors for the intervention site, especially where the human activities are relevant factors of environmental pressure (Beccali M, 2003). Quality of people’s life is affected by energy systems as it could have been used for the creation of parks and recreation centers. The excavations, tunnels and other work necessary for energy systems operation destabilize the flora, the fauna and the ecosystem in general. Different energy systems occupy different land while the products are same. Particularly energy supply systems with biomass and biofuels require the large amount of land. Land use is necessarily considered to energy DM.

3.1.4. Social criteria

Social aspects were definitely the most important criteria for people’s acceptance of energy systems during the past decades.

a- Social acceptability

Social acceptability expresses the overview of opinions related to the energy systems by the local population regarding the hypothesized realization of the projects under review from the consumer point of view. It is extremely important since the opinion of the population and of pressure groups may heavily influence the amount of time needed to go ahead with and complete an energy project. Social acceptance is not expressed as a measurable figure. It is not a quantitative criteria but a qualitative one. Qualitative measures of alternatives against the criteria can be obtained according to the results of the survey carried
out in the local community or city. Social acceptability was employed to analyze their feasibilities of CHP, renewable energy power plants, etc. (Liposcak M, 2006).

**b- Job creation**

Energy supply systems employ many people during their life cycle, from construction and operation till decommissioning. The energy systems are closely related to the society shown in figure 1. Local societies where energy systems were established based their development and prosperity on them for many decades. The sustainable energy system creating more jobs for people is beneficial to improve the living quality of local peoples. In the DM process of local governments, job creations of energy systems are indispensably considered and are selected to evaluate their contributions (Wang et al, 2009).

**Table 3.1**: Summary of main energy projects criteria (Wang et al 2009)

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Criteria</th>
</tr>
</thead>
</table>
| Technical   | Efficiency
              Exergy efficiency
              Primary energy ratio
              Safety
              Reliability
              Maturity
              Others |
| Economic    | Investment cost
              Operation and maintenance cost
              Fuel cost
              Electric cost
              Net present value (NPV)
              Payback period
              Service life
              Equivalent annual cost (EAC)
              Others |
| Environmental | NOx emission
                     CO2 emission
                     CO emission
                     SO2 emission
                     Particles emission
                     Non-methane volatile organic compounds (NMVOCs)
                     Land use
                     Noise
                     Others |
| Social      | Social acceptability
                     Job creation
                     Social benefits
                     Others |
3.1.5 The selected criteria in this study

After listing the most energy evaluation criteria that were utilised by previous studies, we selected the following criteria that are presented in table 3.2.

Table 3.2: The selected criteria

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Criteria</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economical</td>
<td>Cost (LCOE)</td>
<td>Jovanovic M, Sustainable development of the Belgrade energy system. Energy 2009</td>
</tr>
<tr>
<td>Technical</td>
<td>Efficiency</td>
<td>Afgan NH, Multi-criteria assessment of new and renewable energy power plants. Energy 2002</td>
</tr>
<tr>
<td></td>
<td>Ability to respond to demand</td>
<td>Dinca C, A multi-criteria approach to evaluate the natural gas energy systems. Energy Policy 2007</td>
</tr>
<tr>
<td>Environmental</td>
<td>Land use</td>
<td>Afgan NH, Sustainability assessment of a hybrid energy system. Energy Policy 2008</td>
</tr>
<tr>
<td></td>
<td>Job creation</td>
<td>Begic F, Sustainability assessment tool for the decision making in selection of energy system—Bosnian case. Energy 2007</td>
</tr>
<tr>
<td></td>
<td>Social acceptability</td>
<td>Cavallaro F, Multicriteria approach to evaluate wind energy plants on an Italian island. Energy Policy 2005</td>
</tr>
</tbody>
</table>

Lately in chapter 4, after creating the performance matrix, the selected criteria will be assessed using least mean squares method and min max deviation method to notice the possibility of eliminating any of the selected sustainability indicators (criteria).

3.2 Methods of criteria selection

There are various criteria to show the performance of energy system. It is not absolute that more and more criteria are helpful to the sustainable energy decision-making. Likewise, less criteria are beneficial to the evaluation of energy systems. Furthermore, there are repeatability and relevancy in the criteria system, such as the inclusion of fuel cost in operation and maintenance cost, and job creations and social benefits of energy project. Generally, the following principles are obeyed to select the “major” criteria used to energy decision-making (Ye YC, 2006):

- Systemic principle: the criteria system should roundly reflect the essential characteristic and the whole performance of the energy systems.
- Consistency principle: the criteria system should be consistent with the DM objective.
- Independency principle. The criteria should not have inclusion relationship at the same level criteria. The criteria should reflect the performance of alternatives from different aspects.
- Measurability principle. The criteria should be measurable in quantitative value as possible or qualitatively expressed.
- Comparability principle. The DM result is more rational when the comparability of criteria is more obvious. Additionally, the criteria should be normalized to compare or operate directly when there are both benefit criteria and cost criteria.

3.2.1 Least mean squares (LMS) method

The principle of LMS method is that one criteria contributes less importance to results and it can be ignored when its performances of alternatives are almost same or near although the criteria is vital in evaluation (Guo YJ. 2007). To lessen its relativity with other criteria, the criteria can be removed. Let

\[ S_j = \sqrt{\frac{1}{m} \sum_{i=1}^{m} (x_{ij} - \bar{x}_j)^2} \quad (j = 1; 2; \ldots; n) \quad (3.1) \]

where \( x_{ij} \) is the i-th sample of the j-th criteria, \( i = 1, 2, \ldots, m \), and

\[ \bar{x}_j = \frac{1}{m} \sum_{i=1}^{m} x_{ij} \quad (3.2) \]

If there exists \( k \) to make \( S_k = \max_{1 \leq j \leq n} \{ S_j \} \) and \( S_k = 0 \), the \( k \) criteria that corresponds to \( S_k \) can be removed. This method can be also used to elicit the selected weights in Section 3 (the m alternative in the selected n criteria form to the new group decision matrix and then the calculated standard deviation in Eq. (3.2) again is normalized to get the weights).

3.2.2 Min max deviation method

Min max deviation method is similar to LMS method. The judgment standard is the deviation values of criteria. The maximum deviation of criteria \( x_j \) can be calculated as

\[ r_j = \max_{1 \leq i \leq m} \{ x_{ij} - x_{lj} \} \quad (3.3) \]

Likewise, if there exists \( k \) to make \( r_k = \max_{1 \leq j \leq m} \{ r_j \} \) and \( r_k \approx 0 \), the \( k \) criteria that correspond to \( r_k \) can be removed. Similarly, this method can be also used to elicit weights.

3.3 Weighting methods

All factors have their internal impact reclassified to a common scale so that it is necessary to determine each criterion’s relative impact in the sustainable energy DM problem. Weight is assigned to the criteria to indicate its relative importance. Different weights influence directly the DM results of energy systems’ alternatives. Consequently, it is necessary to obtain the rationality and veracity of criteria weights. Three factors are usually considered to obtain the weights: the variance degree of criteria, the independency of criteria, and the subjective preference of the decision-makers. Generally there are two methods: the equal weights and the rank-order weights.
a-Equal weights method

The criteria weight in equal weights method is defined as

\[ w_i = \frac{1}{n} \quad ; i = 1; 2; \ldots ; n \]  \hspace{1cm} (3.4)

The method requires minimal knowledge of the decision maker’s priorities and minimal input from decision maker. The equal weights method was popularized and applied in many decision-making problems since Dawes and Corrigan argued that this method often produced the results nearly as good as those optimal weighting methods in 1974. Equal weights method is the most popular in sustainable energy DM (Wang et al., 2009).

3.3.1. Subjective weighting methods

Subjective weighting methods such as pair-wise comparison (Mamlook R, Wang J-J, 2008). AHP and Simos, were the most used methods in sustainable energy DM. Especially, priority given to one indicator with others being the same was employed to protrude the performances in one aspect in literatures (Pilavachi PA, 2009). The following part introduces briefly several representative subjective weighting methods.

a- Simple multi-attribute rating technique (SMART)

SMART was originally described as the whole process of rating alternatives and weighting criteria by Edwards in 1977. The participants are asked to rank the importance of the changes in the criteria from the worst criteria levels to the best levels. Then they assign 10 points to the least important criteria, and increasing number of points (without explicit upper limit) are assigned to the other criteria to address their importance relative to the least important criteria. The weights are calculated by normalizing the sum of the points to one. Edwards and Barron listed the shortcomings, stressed that weights should clearly be related to the criteria ranges in 1994 (Edwards W, 1994) and presented an improved version, SMARTER. The idea of SMARTER is to use the centroid method so that the weight of a criteria ranked to be it his

\[ W_i = \frac{1}{n} \sum_{k=i}^{n} \frac{1}{k} \]  \hspace{1cm} (3.5)

b- SWING

With the SWING weighting method (Jia JM, 1998), the decision maker begins by rank ordering criteria in terms of their associated value ranges. First the respondent is asked to select the criteria that he would most prefer to change from its worst to its best level and to assign 100 points to these most important criteria. Then the respondent is continued to choose the criteria change from the worst to the best level which he considers to be the second most desirable improvement and to assign points less than 100 to that criteria change. Proceeding in this fashion, the decision maker ranks all criteria and assigns relative
importance points to their value ranges. Finally the given points are normalized to sum up to one to get the criteria weights. The SWING method is an algebraic, decomposed, direct procedure.

c- Pair-wise comparison

In the pair-wise comparison method, participants are presented a worksheet and are asked to compare the importance of two criteria at a time: “Which one of these two criteria is more important, and how much more important?” Then the relative importance is scored. The scales can be various, for example, a scale of 0 (equal importance) to 3 (absolutely more important) is commonly adopted. The results are consolidated by adding up the scores obtained by each criteria when preferred to the criteria it is compared with. The results are then normalized to a total of 1.0. This weighting method provides a framework for comparing each criteria against all others, and helps to show the difference in importance between criteria. However, it does not allow you to check the consistency of participants’ preferences, especially, their transitivity. You should therefore examine the results’ matrices for each participant to check for major problems.

3.3.2 Objective weighting methods

The objective weighting method elicits the criteria weights using the measurement data and information and reflects the difference degree. The literatures about objective weighting methods applied in sustainable energy DM are seldom in the reviewed published papers while the objective weighting methods were widely applied to other evaluation systems, such as social and ecological systems. Only entropy method was employed to elicit the weights (Wang J-J, 2008) in energy projects. The typical objective weighting methods are presented as follows.

a- Entropy method

The entropy shows that how much the criteria reflects the information of system and how great the uncertainty of criteria is. A vector of $x_j = (x_{1j}; x_{2j}; \ldots; x_{mj})$ characterizes the set $X$ in terms of the i-th criteria, defined as follows:

$$X_j = \sum_{i=1}^{m} x_{ij}, \ j = 1, 2, \ldots, m$$

(3.6)

Then the entropy measure of j-th criteria contrast intensity is:

$$e_j = \frac{1}{\ln m} \sum_{i=1}^{m} \frac{d_{ij}}{D_j} \ln \frac{d_{ij}}{D_j}$$

(3.7)

Finally, the normalized weights can be calculated as:

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)}$$

(3.8)
b- Technique for order preference by similarity to ideal solution (TOPSIS) method

The principle of TOPSIS (Hwang CL, 1981) is that the selected best alternative should have the shortest distance from the positive ideal solution in geometrical sense. The weighted distance between alternative \( A_i \) and the ideal solution \( A^* \) is defined as follows:

\[
hi = \sum_{j=1}^{n} w_j^2 (x_{ij} - x_{ij}^*)^2 
\]  

(3.9)

Then the following optimal model is solved and the weights can be elicited.

\[
\text{Min } \sum_{i=1}^{m} h_i = \sum_{i=1}^{m} \sum_{j=1}^{n} w_j^2 (x_{ij} - x_{ij}^*)^2 \\
\text{ s.t. } \sum_{j=1}^{n} w_j = 1, w_j \geq 0
\]  

(3.10)

3.3.3 Combination weighting methods

Combination weighting methods were gradually applied to the evaluation and comparison of complex systems, including energy projects. The methods have two basic combinations: multiplication synthesis and additive synthesis. The principle of multiplication synthesis is expressed as

\[
w_j = \frac{w_{1j} w_{2j}}{\sum_{j=1}^{n} w_{1j} w_{2j}}
\]  

(3.11)

Where \( w_{1j}, w_{2j} \) and \( w_j \) are subjective weight, objective weight and combination weight of the jth criteria respectively. While the additive synthesis is written as

\[
w_j = k w_{1j} + (1 - k) w_{2j}
\]  

(3.12)

Where; \( k \) is the linear combination coefficient and \( k \geq 0 \). The combination coefficient can be determined by various methods, such as optimization based on sum of squares, minimum bias and relational coefficient of gradation. For example, the linear combination coefficient was solved in Jaynes maximal entropy theory and the optimization method and the criteria weights were obtained to be used to select the best CCHP scheme from alternatives (Wang J-J, 2008).

3.3.4 Weighting the selected criteria

It has been argued that using equal weights of ten produces results nearly as good as optimal weighting methods (Dawes and Corrigan, 1974). This is the most popular approach used in sustainable energy assessments due to the minimal additional input required to conduct the analysis (Wang et al., 2009). In order to compensate for the potential short comings of the equal weights approach, the rank-order weighting method has been utilized. This implies that different weights should be attributed to the various
indicators, so that \( w_1 z_1 w_2 z_2 \ldots w_n z_n \), and \( \sum_{i=1}^{n} w_i = 1 \). In this thesis, we opted for a subjective rank-order weighting of the sustainability indicators. The specific approach was an adaptation of the SWING method as it is described by Wang et al. (2009). A questionnaire asking respondents to rate the 7 indicators on a scale of 1–10 based on their importance for the long-term development of mankind (1—not important at all, 10—very important). In order to compensate for the “lack of knowledge” issue specific to subjective weighting, the respondents were asked to assess their own level of familiarity with the issues concerning renewable and hybrid energies. The Survey was done by 27 participants (from universities, research centres and industries). A relatively distribution was also observed among the four main academic ranks (Assistant 15%, Lecturer 31%, Associate professor 35%, Professor 19%). The weight assigned to the ten sustainability indicators were calculated by normalizing and averaging the importance scores given to each of them.

![Figure 3.2: distribution four the main academic ranks.](image1)

![Figure 3.3: weighting of criteria selected](image2)
3.4 Multi-criteria decision analysis methods

It is the turn to determine the preference orders of alternative after determining the criteria weights so that MCAD methods are employed to get the ranking order. In the referred literatures, the comparisons of renewable energy plants and the DM of energy policy. Also summaries all related MCDA methods that are divided into three categories: elementary methods, methods in unique synthesizing criteria and outranking methods. An overview of several typical MCDA methods in energy systems is provided here.

3.4.1 Elementary methods

The former three methods are defined as non-preference information methods without decision maker, and other methods are multi attribute information methods with decision maker. Conjunctive and disjunctive methods belong to screening methods that the acceptable alternative must exceed given performance thresholds for all criteria. Lexicographic, elimination by aspects and linear assignment method are ordinal partiality methods. The latter two methods need the criteria preference of decision maker.

a- Weighted sum method (WSM)

WSM is the most commonly used approach in sustainable energy systems (Renn O.2003) The score of an alternative is calculated as:

$$S_i = \sum_{j=1}^{n} w_j x_{ij}, \quad i = 1, 2, \ldots, m \tag{3.13}$$

Then the resulting cardinal scores for each alternative can be used to rank, screen, or choose an alternative. The best alternative is the one whose score is the maximum.

b- Weighted product method (WPM)

The WPM is similar to WSM. The main difference is that instead of addition in the calculation there is multiplication. The score of alternative $i$ can be calculated as:

$$s_i = \prod_{j=1}^{n} x_{ij}^{w_j}, \quad i = 1, 2, \ldots, m \tag{3.14}$$

Naturally, the alternative having the maximum score is the best scheme. Because of the exponent property, this method requires all ratings be greater than 1. For example, when a criteria has fractional ratings, all ratings in that criteria are multiplied by $10^m$ to meet this requirement. Alternative scores obtained by the weighted product method do not have a numerical upper bound. The decision maker may also not find any true meaning in those scores. Hence, it may be convenient to compare each alternative score with the standard score. If an alternative is compared to the ideal alternative for the only comparison purpose, the ratio is given by:

$$R_i = \frac{s_i}{s^*} = \frac{\prod_{j=1}^{n} x_{ij}^{w_j}}{\prod_{j=1}^{n} (x_j^*)^{w_j}}, \quad i = 1, 2, \ldots, m \tag{3.15}$$
Where $x_j$ is the most favorable performance for criteria j. It is found clearly that the preference of alternative i increase when Reproaches to 1.

3.4.2 Unique synthesizing criteria methods

a- AHP

AHP is widely used for practical MCDA method in various domains, such as social, economic, agricultural, industrial, ecological and biological systems, in addition to energy systems (Wang et al., 2009). It is a descriptive decision analysis methodology that calculates ratio-scaled importance of alternatives through pair-wise comparison of evaluation criteria and alternative. It involves decomposing a complex decision into a hierarchy with goal (objective) at the top of the hierarchy, criteria and sub-criteria at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy. AHP is a type of weighted sum method. The weights obtained in AHP method are introduced in Section 3.1. After obtaining the weights, each performance at the given level is then multiplied with its weight and then the weighted performances are summed to get the score at a higher level. The procedure is repeated upward for each hierarchy, until the top of the hierarchy is reached. The overall weight with respect to goal for each decision alternative is then obtained. The alternative with the highest score is the best alternative.

3.4.3 The outranking methods

The foundation of the outranking methods is the construction and the exploitation of an outranking relation that is introduced by Roy. An outranking relation is a binary relation $S$ defined on the set of alternatives $A$ such that for any pair of alternatives $A$: $A_i S A_k$ if, given what is known about the preferences of the decision maker, the quality of the evaluations of the alternatives and the nature of the problem under consideration, there are sufficient arguments to state that the alternative $A_i$ is at least as good as the alternative $A_k$, while at the same time no strong reason exists to refuse this statement. Compared to the other multi-criteria evaluation methods, the outranking methods have the characteristic of allowing incomparability between alternatives. This characteristic is important in situations where some alternatives cannot be compared for one or another reason.

a- Elimination et choice translating reality (ELECTRE) method

Elimination et choice translating reality (ELECTRE) method was proposed by Benayoun, Roy and Sussman in 1966 and it was developed and improved by Roy in 1971 (Roy B., 1973). Up to now, ELECTRE families have included ELECTRE I, II, III, IV, TRI and some improved ELECTRE methods. For most ELECTRE methods, there are two main stages. These are the construction of the outranking
relations and the exploitation of these relations to get the final ranking of the alternative. Different ELECTRE methods may be different in how they define the outranking relations between alternatives and how they apply these relations to get the final ranking of the alternatives.

ELECTRE concentrates the analysis on the dominance relations among the alternatives. The basic concept of ELECTRE is how to deal with outranking relation by using pair-wise comparisons among alternatives under each criterion separately. It is based on the study of outranking relations, exploitation notions of concordance. These outranking relations are built in such a way that it is possible to compare alternatives. It uses concordance, discordance indexes and threshold values to analyze the outranking relations among the alternatives. The concordance index for a pair of alternatives $A_i$ and $A_k$ measures the strength of the hypothesis that alternative $A_i$ is at least as good as alternative $A_k$. There are no unique measures of concordance. In ELECTRE II, the concordance index $C(A_i, A_k)$ for each pair of alternatives $(A_i, A_k)$ is defined as follows:

$$C(A_i, A_k) = \frac{\sum_{j \in Q(A_i, A_k)} w_i}{\sum_{j=1}^{n} w_i}$$ (3.16)

where $Q(A_i, A_k)$ is the set of criteria for which $A_i$ is equal or preferred to (i.e., at least as good as) $A_k$, and $w_j$ is the weight of the jth criteria. The discordance index $D(A_i, b)$ is defined as follows:

$$D(A_i, b) = \frac{\max_{j \in Q'(A_i, b)} |x_{bi} - x_{Aj}|}{\max_{j=1}^{n} |x_{bj} - x_{Aj}|}$$ (3.17)

where $x_{aj}$ and $x_{bj}$ represent the performances of alternative $A_i$ and $A_k$ in terms of criteria $j$ respectively, $Q'(A_i, A_k)$ is the set of criteria for which $A_i$ is worse than $A_k$, and $n$ is the number of criteria. The formula can be only used when the scores for different criteria are comparable.

After computing the concordance and discordance indices for each pair of alternatives, the graphs for strong and weak relationship can be painted respectively by comparing these indices with the threshold values. Then these graphs are employed to obtain two complete preorders based on descending and ascending distillation chains. Finally, the comparison of the two complete preorders is used to elaborate the final ranking order of alternatives.

ELECTRE methods are sometimes unable to identify the preferred alternative, and in this case, they produce a core of leading alternatives. Such methods have been widely used in energy DM (Wang et al., 2009). ELECTRE methods are particularly convenient when encountering a few criteria with a large number of alternatives in a DM problem.
Example of ELECTRE 3

The following example illustrates clearly how the ELECTREE methods work:

<table>
<thead>
<tr>
<th>Table 3.3: Performance matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Project 1</td>
</tr>
<tr>
<td>Project 2</td>
</tr>
<tr>
<td>Project 3</td>
</tr>
</tbody>
</table>

F : financial (cost and financial return)

RM: risk management (risk of plant failure and damage following natural disaster)

E : environmental (effect on relationship with resource partners and access to resources).

Using thresholds, the ELECTRE method seeks to build an outranking relation $S$. To say $a S b$ means that “a is at least as good as b” OR “a is not worse than b.” Each pair of alternatives $a$ and $b$ is then tested in order to check if the assertion $a S b$ is valid or not. This gives rise to one of the following four situations:

- $a S b$ and not $(b S a)$;
- not $(a S b)$ and $b S a$;
- $a S b$ and $b S a$;
- not $(a S b)$ and not $(b S a)$.

Note that the third situation corresponds to indifference, while the fourth corresponds to incomparability.

The test to accept the assertion $a S b$ is implemented using two principles:

A concordance principle which requires that a majority of criteria, after considering their relative importance, is in favour of the assertion – the majority principle, and

A non discordance principle which requires that within the minority of criteria which do not support the assertion, none of them is strongly against the assertion - the respect of minorities principle.

The operational implementation of these two principles is now discussed, assuming that all criteria are to be maximized. We first consider the outranking relation defined for each of the $r$ criteria; that is, $a S_j b$ means that “a is at least as good as b with respect to the $j$th criterion,” $j = 1,\ldots,r$.

The $j$th criterion is in concordance with the assertion $a S b$ if and only if $a S_j b$. That is, if $g_j(a) \geq g_j(b) - q_j$.

Thus, even if $g_j(a)$ is less than $g_j(b)$ by an amount up to $q_j$, it does not contravene the assertion $a S_j b$ and therefore is in concordance.

The $j$th criterion is in discordance with the assertion $a S b$ if and only if $b P_j a$. That is, if $g_j(b) \geq g_j(a) + P_j$.

Casually speaking, these concepts of concordance and discordance can be thought of as “harmony” and “disharmony.” For each criterion $j$ we are looking to see whether, for every pair of alternatives $(a,b) \in A$, there is harmony or disharmony with the assertion $a S b$; that is, $a$ is at least as good as $b$. With these
concepts it is now possible to measure the strength of the assertion \( a \preceq b \). The first step is to develop a measure of concordance; as contained in the concordance matrix \( C(a,b) \), for every pair of alternatives \((a, b) \in A\). Let \( k_j \) be the importance coefficient or weight for criterion \( j \).

We define a valued outranking relation as follows:

\[
C_j(a, b) = \frac{1}{k} \sum_{j=1}^{r} k_j c_j(a, b)
\]

Where \( k = \sum_{j=1}^{r} k_j \)

Where:

\[
C(j, b) = \begin{cases} 
1 & \text{if } g_j(a) + q_j \geq g_j(b) \\
0 & \text{if } g_j(a) + p_j \leq g_j(b) \\
\frac{p_j + g_j(a) - g_j(b)}{p_j - q_j}, & \text{otherwise}
\end{cases}
\]

Using data from Table 1, we calculate the concordance index for the pair of projects P1 and P3. First, we define the thresholds and weights, as in Table 2.

**Table 3.4: Thresholds and Weights**

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>RM</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indifference thresholds (q)</td>
<td>25</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Preference thresholds (p)</td>
<td>50</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>weights</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The value of 0.667 measures the strength of the assertion that P2 is at least as good as P5. Table 3.3 presents the complete concordance matrix:

\[
C_1(P1, P3) = 1 \quad \text{since } 129+25 \geq -14
\]

\[
C_2(P1, P3) = 0.333 \quad \text{since } 0+12 \geq 20 \text{ and } 0+24 \leq 20 \text{ then } (24+0-20)/24-12 = 0.333
\]

\[
C_3(P1, P3) = 0 \quad \text{since } 0+30 \leq 40
\]

Therefore \( C(P1, P3) = \frac{(1*1)+(1*0.333)+(1*0)}{1+1+1} = 0.444 \)

The value of 0.444 measures the strength of the assertion that P1 is at least as good as P3. Table 3 presents the complete concordance matrix.
Table 3.5: Concordance Matrix

<table>
<thead>
<tr>
<th></th>
<th>Project 1</th>
<th>Project 2</th>
<th>Project 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>1</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>Project 2</td>
<td>0.58</td>
<td>1</td>
<td>0.66</td>
</tr>
<tr>
<td>Project 3</td>
<td>0.66</td>
<td>0.66</td>
<td>1</td>
</tr>
</tbody>
</table>

These concordance values are easily interpreted. Since equal weights were used, the concordance value is simply the percentage of criteria where one alternative is at least as good as the other. For example, a value of 0.44 for C(P1,P2) means that for two out of three criteria, P1 was at least as good as P2. Only for the financial criterion F was P2 strictly preferred to P1; that is, the difference exceeded the preference threshold of 50.

Thus far, no consideration has been given to the discordance principle. In the concordance matrix, we have, in a manner of speaking, a measure of the extent to which we are in harmony with the assertion that a is at least as good as b. But what disconfirming or “disharmonious” evidence do we have? In other words, is there any discordance associated with the assertion a \( \preceq b \)?

To calculate discordance, a further threshold called the veto threshold is defined. The veto threshold, \( v_j \), allows for the possibility of a \( \preceq b \) to be refused totally if, for any one criterion \( j \), \( g_j(b) > g_j(a) + v_j \). The discordance index for each criterion \( j \), \( d_j(a,b) \) is calculated as: evidence do we have? In other words, is there any discordance associated with the assertion a \( \preceq b \)? To calculate discordance, a further threshold called the veto threshold is defined. The veto threshold, \( v_j \), allows for the possibility of a \( \preceq b \) to be refused totally if, for any one criterion \( j \), \( g_j(b) > g_j(a) + v_j \). The discordance index for each criterion \( j \), \( d_j(a,b) \) is calculated as:

\[
d_j(a,b) = \begin{cases} 
0 & \text{if } g_j(a) + v_j \leq g_j(b) \\
1 & \text{otherwise}
\end{cases}
\]

As shown in Table 4, we assume veto thresholds for each criterion.

Table 3.6: Veto Thresholds

<table>
<thead>
<tr>
<th>Veto threshold (V)</th>
<th>F</th>
<th>RM</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>48</td>
<td>90</td>
</tr>
</tbody>
</table>

Consider criterion F, with a veto threshold of 100. We compare projects P1 and P3. It is clear that:

\[ g_F(P1) > g_F(P3) + V_F \quad \text{or} \quad 129 > -14 + 100 \]

Therefore, the discordance index \( d_F(P1,P2) = 1.00 \). A discordance matrix is produced for each criterion. Unlike concordance, no aggregation over criteria takes place; one discordant criterion is sufficient to discard outranking.
For each pair of projects \((a,b) \in A\), there now exists a concordance and a discordance measure. The final step in the model building phase is to combine these two measures to produce a measure of the degree of S(a,b) =

\[
\begin{cases} 
  c \ (a, b), & \text{if } d_j \leq C(a, b) \forall j \\
  C(a, b) \prod_{j \in J(a,b)} 1 - \frac{d_j(a, b)}{1-C(a,b)} \\
\end{cases}
\]

(3.21)

where \(J(a,b)\) is the set of criteria such \(d_j(a,b) > C(a,b)\)

This formula assumes that if the strength of the concordance exceeds that of the discordance, then the concordance value should not be modified. Otherwise, we are forced to question the assertion that \(a\) \(\text{S}\) \(b\) and modify \(C(a,b)\) according to the above equation. If the discordance is 1.00 for any \((a,b) \in A\) and any criterion \(j\), then we have no confidence that \(a\) \(\text{S}\) \(b\); therefore, \(S(a,b) = 0.00\). The credibility matrix for this example is:

### Table 3.7: Credibility Matrix

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>1</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>Project 2</td>
<td>0.58</td>
<td>1</td>
<td>0.66</td>
</tr>
<tr>
<td>Project 3</td>
<td>0.66</td>
<td>0.66</td>
<td>1</td>
</tr>
</tbody>
</table>

Outranking; that is, a credibility matrix which assesses the strength of the assertion that “\(a\) is at least as good as \(b\).” The credibility degree for each pair \((a,b)\) in \(A\) is defined as:

Let \(\lambda = S(a,b)\). Determine a “credibility value” such that only values of \(S(a,b)\) that are sufficiently close to \(\lambda\) are considered; that is, \(\lambda - s(\lambda)\). Thus if \(\lambda = 1\), let \(s(\lambda) = 0.15\). (Detailed computations for the values of \(s(\lambda)\) are provided with the ELECTRE III software (Vallée and Zielniewicz, 1994). Define the matrix \(T\) as:

\[
T(a,b) = \begin{cases} 
1, & \text{if } S(a, b) > \lambda - s(\lambda) \\
0, & \text{otherwise} 
\end{cases}
\]

(3.22)

Further, define the qualification of each project - \(Q(a)\) - as the number of projects that are outranked by Project a minus the number of projects which outrank Project a. \(Q(a)\) is simply the row sum minus the column sum of the matrix \(T\). The set of alternatives having the largest qualification is the first distillate of \(D_1\). If \(D_1\) contains only one alternative, repeat the previous procedure with \(A \setminus D_1\). Otherwise, apply the same procedure inside \(D_1\). If distillate \(D_2\) contains only one alternative, the procedure is started in \(D_1 \setminus D_2\).
(unless the set is empty); otherwise it is applied within $D_2$, and so on until $D_1$ is used up. The procedure is then repeated starting with $A \setminus D_1$. The outcome is the first preorder $Z_1$; the descending distillation. The ascending distillation is carried out in a similar fashion except that the projects with the smallest (rather than the largest) qualification are retained first. For this example, the two distillations give the following preorders, as shown in Figure 3.4.

![Figure 3.4: result of example.](image)

**b- Preference ranking organization method for enrichment evaluation (PROMETHEE)**

PROMETHEE method developed by Brans (Brans JP, 1984) has been used in energy planning and applications, such as geothermal energy project renewable (Madlener R, 2007) energy exploitation. This method uses the outranking principle to rank the alternatives, combined with the ease of use and decreased complexity. It is well adapted to problems where a finite number of alternatives are to be ranked considering several, sometimes-conflicting criteria. The principle is the construction and the exploitation of a valued out ranking relation $p$. Two complete pre orders can be obtained by ranking the alternatives according to their incoming flow and their outgoing flow. The intersection of these two pre orders yields the partial pre order of PROMETHEE I where incomparability’s are allowed. The ranking of the alternatives according to their net flow yields the complete pre order of PROMETHEE II. Like to ELECTRE method, it also performs a pair-wise comparison $n$ of alternatives in order to rank them with respect to a number of criteria. However, ELECTRE method only pay attention to the preference and ignore the difference level between alternatives when determining the ranking order. PROMETHEE introduces the preference functions to measure the difference between two alternatives for any criteria. Brans have offered six generalized criteria functions including usual criteria, quasi criteria, criteria with linear preference, level criteria, criteria with linear preference and indifference, and Gaussian criteria.

Multi-criteria preference index for a pair of alternatives $A_i$ and $A_k$ is defined as

$$\pi(A_i, A_k) = \frac{\sum_{j=1}^{n} w_j p_j(A_i, A_k)}{\sum_{j=1}^{n} w_j} \quad (3.23)$$

Where $p_j (a,b)$ is the preference functions for alternatives $a$ and $b$. Then the incoming flow is calculated as:

$$\phi^+(A_i) = \sum_{k=1}^{m} \pi(A_i, A_k), k = 1, 2, \ldots, m \quad (3.24)$$

and the outgoing flow is calculated as:

$$\phi^-(A_i) = \sum_{k=1}^{m} \pi(A_i, A_k), k = 1, 2, \ldots, m \quad (3.25)$$

Finally, the net flow is equal to the difference of incoming flow and outgoing flow. After obtaining all net flows of alternatives, the alternative having maximum net flow is considered as the best.
3.5. Aggregation methods

Usually, the decision maker selects the best alternative based on the ranking orders after the calculation in a selected MCDA method. However, the creditability of DM is necessarily verified so that the results of the ranking orders are computed by a few MCDA methods sometimes. The application of various MCDA methods of calculation may yield different results (preference ranking order). The question “which method is most suitable to solve the problem?” is most important, but difficult to answer. Therefore, the ranking results are necessarily aggregated again and the best scheme from the alternatives is selected. The methods used to aggregate the preference orders are called as aggregation methods in this article. In the reviewed papers, there is little consideration on about aggregation methods in energy DM while the aggregation methods were applied in social and economic systems (Guo YJ.2007). The aggregation methods can be divided into two categories: voting method and mathematical aggregation method. The mathematical aggregation methods are classified to two sub-categories, “hard aggregation method” and “soft aggregation method” based on with or without the decision-makers.

3.5.1. Voting methods

A very general approach to aggregating alternatives’ preferences is the voting methods. The winning alternative in voting methods depends on which voting rule is used. Generally, Borda rule and Copeland rule (Conitzer V.2006) are the most common voting rules.

a- Borda:

Borda rule is to select the option that on average stands highest in the voters’ rankings. Firstly, assign points to them alternatives in the individual preferences, namely m _ 1 points for the top ranked alternative, m _ 2 points for the second ranked alternative, down to 0 points for the bottom ranked alternative; then add up those points over all individuals for every alternative; Finally the more points an alternative receives the higher ranked it is in the social preference.

b- Copeland

Copeland rule is to select the option (if one exists) that beats each other option in exhaustive pair-wise comparison. Firstly, calculate the number of alternatives it beats by a majority and the number of alternatives it loses against for each alternative; then calculate the difference between the two numbers; finally, the larger the number the higher ranked is the alternative in the social preference.

3.5.2. Mathematical aggregation methods

a- Hard aggregation methods

“Hard aggregation methods” mean that the aggregating results cannot require the decision-maker and are obtained in mathematical methods over the ranking orders of alternatives, which avoid the preference
of decision-makers. The aggregating results have strong objectivity and the selected scheme is compelling. The basic aggregation method is the average method and the developed aggregation methods include vertical and horizontal aggregation method, and singular value decomposition aggregation method. The principle of vertical and horizontal aggregation method is similar to the method in Section 3.2.3 and it is also an optimal method based on the ranking orders or the evaluation scores of alternatives. The singular value decomposition aggregation method has been employed to analyze the feasibility of combination weighting method for criteria of CHP and the principle applied to aggregation of ranking orders is same.

b- Soft aggregation methods

“Soft aggregation methods” require the decision-maker and the final results are obtained through the negotiation of decision makers when there are difference or collision of opinion. The method embodies the flexible decision that makes the majority of decision-makers satisfied. The “soft aggregation methods” are more seldom in practical application. Yi et al. proposed the aggregation methods treating the multi-evaluation conclusions characterized by disagreement and conflict (Yi PT, 2006).
**Conclusion**

The multi-criteria and decision analysis (MCDA) methods is the main method to help the decision makers in ranking the best alternatives. This method has a many steps:

1. Criteria selection (efficiency, Safety and human health, Ability to respond to demand, Land use, Job creation, Social acceptability, Cost (LCOE)).
2. Weighting of criteria (LMS, Min-max).
3. Apply the ranking the alternative methods. (ELECTREE, Multi utility)
4. Aggregation about the results
Chapter 4: Application on a case study
Chapter 4: Application on a case study

4.1 Case of wilaya of Ouargla

Ouargla is located on south east of Algeria (figure 4.1), and it has a surface area of about 211 980 km². The population is around 633 967 habitants. Ouargla has a hot desert climate, long hot summers and short cold winters. Averages high temperatures in summer are consistently over 40 °C for nearly 4 months (June, July, August and September) and reach a maximum of around 45 °C in July. Averages low temperatures in summer are also very high, and are above 27 °C and routinely above 30 °C during the hottest month.

Figure 4.1: Location of Ouargla (google earth image)

4.1.1 The biggest cities in wilaya of Ouargla

From the points of view of population, number of buildings, economic and electricity consumption, there are three main cities in wilaya of ouargla: Ouargla, Touggourt, Hassi messaoud.

Ouargla city is about 850 km to the south east of the capital Algiers. It is the largest city in the wilaya. Its height is about 165m above the sea level. It has a population of about 210 175 people. Ouargla is surrounded by exploited oil and gas fields, as well as many palm tree oases. Very promising projects in agriculture domain are actually been developing.

Touggourt city is situated on the north east of the wilaya, 160 km from Ouargla city, with a population of roughly 300,000 people. Its height is about 85m above the sea level. It is the second biggest city in Ouargla. Built around an oasis, Touggourt’s economy is based mainly on agriculture with dates being one of their biggest exports. Cereals, vegetables, carpets and cloth also play a large role in the economy.
Hassi messaoud city is 85 km to the south east of Ouargla. Its height is about 463m above the sea level. It has a population of about 45,147 people. It is the largest city in hydrocarbon activities, with the main fields of oil.

4.1.2 The main resources of renewable energies in Ouargla

The flowing table summarise the main resources of renewable energies in Wilaya of Ouargla (for the three biggest cities that mentioned previously in section 4.1.1).

<table>
<thead>
<tr>
<th>Resource</th>
<th>City</th>
<th>Ouargla</th>
<th>Touggourt</th>
<th>Hassi Messouad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar radiation (Mwh/year)</td>
<td></td>
<td>2.2</td>
<td>1.9</td>
<td>2.1</td>
</tr>
<tr>
<td>Wind speed (m/s)</td>
<td></td>
<td>3.5</td>
<td>3.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Geothermal (C°/100m)</td>
<td></td>
<td>4.64</td>
<td>3.78</td>
<td>4.5</td>
</tr>
<tr>
<td>Biomass (TOE)</td>
<td></td>
<td>278341</td>
<td>390816</td>
<td>—</td>
</tr>
</tbody>
</table>

4.1.3 Valuation of the assessed technologies

In this part of the study, some criteria are calculated, for example, the cost of renewable energy project (LCOE). Other criteria data have been collected from different resources and the unavailable data were assumed to be identical among similar technologies (see appendix). All those criteria values come together to generate the performance matrix.

In the first case, the percentage of renewable energies in hybrid technologies were assumed to be 50% // 50%, therefore, all the criteria were calculated based on these percentages (see appendix).
### Table 4.2: Performance matrix of the assessed technologies (see appendix)

<table>
<thead>
<tr>
<th>Technologies</th>
<th>LCOE Cost ($/MWh)</th>
<th>Ability to respond to demand</th>
<th>Efficiency (%)</th>
<th>Land use (m²/MWh)</th>
<th>Safety and human health costs (£/MWh)</th>
<th>Job creation (job-years/MWh)</th>
<th>Social acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar thermal</td>
<td>206.90</td>
<td>Yes, slow</td>
<td>40.00</td>
<td>0.46</td>
<td>0.44</td>
<td>0.23</td>
<td>High</td>
</tr>
<tr>
<td>Solar PV</td>
<td>129.20</td>
<td>No</td>
<td>100.00</td>
<td>0.33</td>
<td>0.44</td>
<td>0.87</td>
<td>High</td>
</tr>
<tr>
<td>Geothermal</td>
<td>63.10</td>
<td>Yes, slow</td>
<td>15.00</td>
<td>0.74</td>
<td>0.50</td>
<td>0.25</td>
<td>High</td>
</tr>
<tr>
<td>Wind</td>
<td>103.30</td>
<td>No</td>
<td>100.00</td>
<td>1.57</td>
<td>0.10</td>
<td>0.17</td>
<td>Medium</td>
</tr>
<tr>
<td>Biomass</td>
<td>51.10</td>
<td>Yes, slow</td>
<td>85.00</td>
<td>0.31</td>
<td>3.20</td>
<td>0.11</td>
<td>Medium</td>
</tr>
</tbody>
</table>

#### Hybrid 50/50

<table>
<thead>
<tr>
<th>Solar thermal</th>
<th>Solar PV</th>
<th>168.05</th>
<th>Yes, slow</th>
<th>70.00</th>
<th>0.40</th>
<th>0.44</th>
<th>0.55</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar thermal</td>
<td>Geothermal</td>
<td>135.00</td>
<td>Yes, rapid</td>
<td>27.50</td>
<td>0.60</td>
<td>0.47</td>
<td>0.24</td>
<td>High</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>Wind</td>
<td>155.10</td>
<td>Yes, slow</td>
<td>70.00</td>
<td>1.02</td>
<td>0.27</td>
<td>0.20</td>
<td>Medium</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>Biomass</td>
<td>129.00</td>
<td>Yes, slow</td>
<td>62.50</td>
<td>0.39</td>
<td>1.82</td>
<td>0.17</td>
<td>Medium</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Geothermal</td>
<td>96.15</td>
<td>Yes, slow</td>
<td>57.50</td>
<td>0.54</td>
<td>0.47</td>
<td>0.56</td>
<td>High</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Wind</td>
<td>116.25</td>
<td>Yes, slow</td>
<td>100.00</td>
<td>0.95</td>
<td>0.27</td>
<td>0.52</td>
<td>Medium</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Biomass</td>
<td>90.15</td>
<td>Yes, slow</td>
<td>92.50</td>
<td>0.32</td>
<td>1.82</td>
<td>0.49</td>
<td>Medium</td>
</tr>
<tr>
<td>Geothermal</td>
<td>Wind</td>
<td>83.20</td>
<td>Yes, slow</td>
<td>57.50</td>
<td>1.16</td>
<td>0.30</td>
<td>0.21</td>
<td>Medium</td>
</tr>
<tr>
<td>Geothermal</td>
<td>Biomass</td>
<td>57.10</td>
<td>Yes, rapid</td>
<td>50.00</td>
<td>0.53</td>
<td>1.85</td>
<td>0.18</td>
<td>Medium</td>
</tr>
<tr>
<td>Wind</td>
<td>Biomass</td>
<td>77.20</td>
<td>Yes, slow</td>
<td>92.50</td>
<td>0.94</td>
<td>1.65</td>
<td>0.14</td>
<td>Medium</td>
</tr>
</tbody>
</table>
4.1.4 Assessment of sustainability criteria

After the valuation stage was complete, an analysis of the results is done in order to establish whether all the chosen indicators are indeed relevant for our study. Based on the approaches used in past research (Wang et al., 2009), we choose the Least Mean Squares and Minimax deviation methods (table 4.3 and 4.4). These methods can be used to establish whether certain indicators have a lower contribution to the ranking calculation (due to limited variance of the characteristic among the different technologies) and should thus be eliminated from the analysis altogether.

Table 4.3: Least mean squares results

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Cost</th>
<th>Ability to respond to demand</th>
<th>Efficiency</th>
<th>Land use</th>
<th>Safety and human health costs</th>
<th>Job creation</th>
<th>Social acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sj</td>
<td>0.0450</td>
<td>0.0547</td>
<td>0.0524</td>
<td>0.0208</td>
<td>0.0225</td>
<td>0.0466</td>
<td>0.0549</td>
</tr>
</tbody>
</table>

So after this result, we could deduce that the criteria have been verified by the least mean square. \( \text{Min } S_j \neq 0 \)

Table 4.4: Min max deviation results

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Cost</th>
<th>Ability to respond to demand</th>
<th>Efficiency</th>
<th>Land use</th>
<th>Safety and human health costs</th>
<th>Job creation</th>
<th>Social acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>rj max</td>
<td>0.0957</td>
<td>0.1021</td>
<td>0.1058</td>
<td>0.0506</td>
<td>0.0615</td>
<td>0.1210</td>
<td>0.1024</td>
</tr>
</tbody>
</table>

The second utilized method in our verification is Min max deviation, which also verifies the chosen criteria. \( \text{Min } r_j \max \neq 0 \)

4.1.5 Criteria weighting

To observe the influence of different criteria weights, firstly, the equal weights method is utilised, which was found in many prior energy planning researches (Wang et al., 2009), therefore, all the criteria have the same weight, which is 14.3% in this case. Then, we use an adaptation of the SWING method as it is described by (Wang et al, 2009). The criteria weights are calculated based on the obtained results from a survey (clearly illustrated in section 3.3.3). The multi utility method is applied to find the following results in figure 4.2, which show very dissimilar results by using equal and different weights. Except wind energy all the other energies don not have the same rank position.
4.1.6 Evaluation stage "using MCAD methods"

a- Application of Multi utility method:

The calculation in multi utility method (see section 3.3.1 a) was done by a simple excel developed programme. The results are presented in figure 4.3.

The result of multi utility method, as it is shown in figure 4.3, appears that Solar PV technology is significantly outranks all other alternatives from an overall sustainability point of view. The next most sustainable technologies are hybrid technologies: Solar PV-Wind, Geothermal-Wind, Solar PV-Biomass, Solar thermal-Solar PV, Wind-Biomass, and Solar thermal-Geothermal. The other renewable technologies come last and the lowest ranked is Wind.
b- Application of ELECTRE 3 method:

The calculation by ELECTRE 3 method (clearly demonstrated in section 3.4.3 a) was in tow steps: the first step is normalising the values of the criteria and calculating the three thresholds; indifference ($q$), preference ($p$), and veto ($v$) using simple excel developed programme.

### Table 4.5: Thresholds

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
</tr>
</thead>
<tbody>
<tr>
<td>q</td>
<td>77.9</td>
<td>1.5</td>
<td>42.5</td>
<td>0.63</td>
<td>1.549</td>
<td>0.38</td>
<td>1</td>
</tr>
<tr>
<td>p</td>
<td>155.8</td>
<td>3.0</td>
<td>85.0</td>
<td>1.26</td>
<td>3.099</td>
<td>0.76</td>
<td>2</td>
</tr>
<tr>
<td>v</td>
<td>311.6</td>
<td>6.0</td>
<td>170.0</td>
<td>2.52</td>
<td>6.198</td>
<td>1.52</td>
<td>4</td>
</tr>
</tbody>
</table>

The second step is using Matlab programme to evaluate and rank the assessed technologies. The results of ELECTRE 3 method are presented in figure 4.4.

![Renewable energies ranking by ELECTREE 3](image)

**Figure 4.4:** Renewable energies ranking by ELECTREE 3

The result of ELECTREE 3 method, as it is shown in figure 4.4, appears that Solar PV technology is also outranks all other alternatives, followed by Solar thermal-Biomass, Geothermal-Biomass, Solar thermal-Geothermal, respectively. Then, Solar PV-Wind and Solar PV-Biomass are the next technologies in this rank followed by Solar PV-Geothermal, Solar thermal-Solar PV and Geothermal-Wind,
respectively. The other renewable technologies come last and the lowest ranked are Solar thermal and Wind.

c- Aggregation method and final ranking:

After presenting the obtained results from Multi utility and ELECTREE 3 methods, it is the turn of decision makers to select the best alternatives using aggregation methods. However, in this case the choice is clear, because both methods gave almost the same results (ranks).


d- Discussion

The technologies final ranking illustrates that all the hybrid renewable technologies outrank the single renewable ones (except Solar PV which take the first position), and that is mainly because of the enhancement in the different indicators such as "the ability to respond to demand" which is better in hybrid than in single technologies. Furthermore, Wind has the lowest position out of all the other renewable energy technologies. This is mainly due to the large required land use and the high cost, in addition to the ability to respond to demand which is the lowest one. Solar thermal is also ranked lowly because of the extremely high cost comparing to other technologies and low efficiency (both have the highest weight).
In the second case, the percentages of renewable energies in hybrid technologies were assumed to vary from one combination to another one. All the criteria were calculated based on these percentages.

**Table 4.4:** Performance matrix of the assessed technologies (see appendix)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Technologies</th>
<th>LCOE Cost ($/MWh)</th>
<th>Ability to respond to demand</th>
<th>Efficiency (%)</th>
<th>Land use (m²/MWh)</th>
<th>Safety and human health costs ($/MWh)</th>
<th>Job creation ( job-years /MWh)</th>
<th>Social acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solar thermal</td>
<td>206.90</td>
<td>Yes, slow</td>
<td>40.00</td>
<td>0.46</td>
<td>0.44</td>
<td>0.23</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Solar PV</td>
<td>129.20</td>
<td>No</td>
<td>100.00</td>
<td>0.33</td>
<td>0.44</td>
<td>0.87</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Geothermal</td>
<td>63.10</td>
<td>Yes, slow</td>
<td>15.00</td>
<td>0.74</td>
<td>0.50</td>
<td>0.25</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Wind</td>
<td>103.30</td>
<td>No</td>
<td>100.00</td>
<td>1.57</td>
<td>0.10</td>
<td>0.17</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Biomass</td>
<td>51.10</td>
<td>Yes, slow</td>
<td>85.00</td>
<td>0.31</td>
<td>3.20</td>
<td>0.11</td>
<td>Medium</td>
</tr>
</tbody>
</table>

**Hybrids with different percentage**

|          | Solar thermal (25%)                   | 168.05            | Yes, slow                    | 70.00          | 0.40              | 0.44                                 | 0.55                          | High                |
|          | Solar PV (75%)                        |                   |                               |                |                   |                                      |                              |                     |
|          | Solar thermal (25%)                   | 135.00            | Yes, slow                    | 27.50          | 0.60              | 0.47                                 | 0.24                          | High                |
|          | Geothermal (75%)                      |                   |                               |                |                   |                                      |                              |                     |
|          | Solar thermal (40%)                   | 155.10            | Yes, slow                    | 70.00          | 1.02              | 0.27                                 | 0.20                          | Medium              |
|          | Wind (60%)                            |                   |                               |                |                   |                                      |                              |                     |
|          | Solar thermal (25%)                   | 129.00            | Yes, slow                    | 62.50          | 0.39              | 1.82                                 | 0.17                          | Medium              |
|          | Biomass (75%)                         |                   |                               |                |                   |                                      |                              |                     |
|          | Solar PV (75%)                        | 96.15             | Yes, slow                    | 57.50          | 0.54              | 0.47                                 | 0.56                          | High                |
|          | Geothermal (25%)                      |                   |                               |                |                   |                                      |                              |                     |
|          | Solar PV (75%)                        | 116.25            | Yes, slow                    | 100.00         | 0.95              | 0.27                                 | 0.52                          | High                |
|          | Wind (25%)                            |                   |                               |                |                   |                                      |                              |                     |
|          | Solar PV (75%)                        | 90.15             | Yes, slow                    | 92.50          | 0.32              | 1.82                                 | 0.49                          | High                |
|          | Biomass (25%)                         |                   |                               |                |                   |                                      |                              |                     |
|          | Geothermal (60%)                      | 83.20             | Yes, slow                    | 57.50          | 1.16              | 0.30                                 | 0.21                          | Medium              |
|          | Wind (40%)                            |                   |                               |                |                   |                                      |                              |                     |
|          | Geothermal (60%)                      | 57.10             | Yes, rapid                   | 50.00          | 0.53              | 1.85                                 | 0.18                          | Medium              |
|          | Biomass (40%)                         |                   |                               |                |                   |                                      |                              |                     |
|          | Wind (60%)                            | 77.20             | Yes, slow                    | 92.50          | 0.94              | 1.65                                 | 0.14                          | Medium              |
a- Application of Multi utility method:

The calculation in multi utility method (see section 3.3.1 a) was done by a simple excel developed programme. The results are presented in figure 4.5.

Figure 4.5: Multi utility method result (hybrid with deferent shares)

The result of multi utility method, as it is shown in figure 4.5, shows that Solar PV technology is not considerably outranks all the alternatives, like the first case, however, Solar PV, Solar PV-Wind, Solar PV-Biomass, Geothermal-Biomass, Geothermal-Wind, and Solar thermal-Solar PV have almost the same position. The next technology is Solar thermal-Geothermal, after that the other combinations. Solar thermal and Wind rank the lowest.
b- Application of ELECTRE 3 method:

The same steps as the first case are followed to evaluate the different renewable technologies. The results of ELECTRE 3 method are presented in figure 4.6.

Figure 4.6: Renewable energies ranking by ELECTREE 3

The result of ELECTREE 3 method, as it is shown in figure 4.5, shows that Solar PV-Biomass, Solar PV-Wind and Solar PV-Geothermal outranks all other alternatives, followed by Solar PV, Solar thermal-Solar PV, Solar thermal-Biomass and Solar thermal-Geothermal, Geothermal-Biomass, Solar thermal-Wind, respectively. The other renewable technologies come last and the lowest ranked energies, as the first case, are Solar thermal and Wind.

c- Aggregation method and final ranking:

d- Discussion

The technologies final ranking also shows that hybrid renewables outrank single renewable technologies and that is mainly because of the enhancement in the different indicators such as "the ability to respond to demand" which is better in hybrid comparing to single technologies. It is also noticed that configurations of Solar PV (75%) with another renewable energies take higher ranks than in first case, with (50%). In general, this is because; this configuration has better criteria values, in addition to the augmentation in "the ability to respond to demand".

In this case, Wind has the lowest position out of all the other renewable energy technologies. Due to the same raison as the first case, mainly the ability to respond to demand Solar thermal is still ranked lowly because of the extremely high cost compared to other renewables.

From the first case (hybrid 50% // 50%) and the second case (hybrid with deferent percentage), we can conclude, which combination between renewable energy make them more competitive comparing to single energy.

Solar PV is one of the most energy production alternatives that can be widely exploited to produce electricity in the south of Algeria. In general, very low ability to respond to demand is the major disadvantages of Solar PV. However, we can overcame it .and inhens this ability by hybrid technology of Solar PV with another type of renewables energy.
Conclusion générale
Conclusion

Until present time at national and global levels, fossil sources are still the principal means of energy production, including oil, coal, gas and nuclear.

Different types of energies including fossil and renewable sources show strong effect of environmental, economic and social indicators on energy production.

Algeria has large reserves of fossil energy sources, mainly oil and gas, and considerable potential of renewable energy sources especially with respect to solar, geothermal and wind power. However the level of development of such energy sources is rather primary, but efforts should increase because of the ever growing concern about the environment friendly sources.

The results of Multi utility and ELECTRE 3 methods were similar in for some technologies and dissimilar for others. The final ranking was an aggregation between the two methods with strong consider to ELECTRE 3.

Among five single renewable energies and ten hybrids which were selected and assessed based on a diversity of the sustainable indicators (criteria), including technical, economic, environmental and social criteria, the results showed that Solar PV is one of the most energy production alternatives that can be widely exploited in the south of Algeria (practically the case of study "Ouargla") to produce electricity. In general, very low ability to respond to demand is the major disadvantage of Solar PV. However, it can be overcome and enhanced by the combination of Solar PV with another type of renewable energy, such as in Solar PV-Biomass, Solar PV-Geothermal.
References
- http://www.mem.alafrica
- International Network for Sustainable Energy (2010)
- Levelised cost of energy from:
- Solar thermal power (2010).
Appendix

Levelised cost of energy production (transparent cost database)

\[
LCOE = \frac{CapitalCost \times CRF \times (1 - TDpv)}{8760 \times CapacityFactor \times (1 - T)} + \frac{fixedO&M}{8760 \times CapacityFactor} + \frac{variableO&M}{1000 \frac{KWh}{MWh}} + \frac{FuelPrice \times HeatRate}{1,000,000 \frac{BTU}{mmBTU}}
\]

<table>
<thead>
<tr>
<th>Term</th>
<th>Units</th>
<th>Description</th>
<th>Alternative Sources</th>
<th>Database Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>US$/Kw</td>
<td>Cost of the plant</td>
<td>Ongh CapitalCostDol per KwInclCtng will be used first, but if not available, the product of the Contingency Factor and OnghCapitalCostDolPerKw will be used, otherwise just Ongh CapitalCostDolPerKw.</td>
<td>Onght CapitalCostDol per KwInclCtng, ContingencyFactor, Onght CapitalCostDol PerKw</td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
<td>Calculated</td>
<td></td>
</tr>
<tr>
<td>CRF</td>
<td></td>
<td>Capital expenditures are annualized into the CRF term defined above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\tau)</td>
<td></td>
<td>Tax rate paid (applied after depreciation credits). It is 39.2%.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D_{PV})</td>
<td></td>
<td>The present value of depreciation, depending on the MACRS schedule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery</td>
<td>1</td>
<td>Fuel Cell: 0.83155</td>
<td>Onshore: 0.83155</td>
<td></td>
</tr>
<tr>
<td>Biopower</td>
<td>0.83155</td>
<td>Hydro: 0.54407</td>
<td>Photovoltaic (PV): 0.83155</td>
<td></td>
</tr>
<tr>
<td>Blind Geothermal: 0.83155</td>
<td>Hydrothermal: 0.83155</td>
<td>Pumped Hydro Storage: 1</td>
<td>Residential PV: 0.83155</td>
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</tr>
<tr>
<td>Blind Geothermal System: 0.83155</td>
<td>Ice Storage: 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combined Cycle: 0.54407</td>
<td>Integrated Gasification Combined Cycle (IGCC): 0.54407</td>
<td>Scrubbed: 0.54407</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combustion Turbine: 0.59476</td>
<td>Land Based Wind: 0.83155</td>
<td>Small Hydropower: 0.83155</td>
<td>Solar Thermal: 0.83155</td>
<td></td>
</tr>
<tr>
<td>Commercial PV: 0.83155</td>
<td>Marine Hydrokinetic: 0.83155</td>
<td>Solar Thermal: 0.83155</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressed Air Energy Storage: 1</td>
<td>Near Field (or Enhanced Hydrothermal): 0.83155</td>
<td>Utility pv: 0.83155</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>Capacity Factor</td>
<td>Description</td>
<td>Formula</td>
<td>Default Value</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>-----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Concentrating Solar Power</td>
<td>0.83155</td>
<td>Yearly average percentage of power as a fraction of capacity</td>
<td>The average capacity factor defined with the data point will be used. If that is not available, the maximum capacity factor is used. Otherwise the default value defined for the technology (please see refer to the “LevelizingParameters” for the default values based on the levelizing mode you have selected).</td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.59476</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unscrubbed</td>
<td>0.54407</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distributed Generation</td>
<td>0.54407</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean</td>
<td>0.83155</td>
<td>Offshore: 0.83155</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>0.54407</td>
<td>Otherwise: 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhanced Geothermal</td>
<td>0.83155</td>
<td>Offshore wind: 0.83155</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geothermal System (egs)</td>
<td>0.83155</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**8760 Hrs/Yr** Number of hours in a year.

**Capacit y Factor**

**All Inclusive O&M** US$/kW Total (fixed and variable) cost of operations and maintenance of the plant, in $/kW.

This value would be used if provided (divided by the product of the Capacity Factor and 8760). If this value is not provided, then the fixed and variable O&M values would be used as shown in the formula above.

**Fixed O&M** US$/kW Fixed operations and maintenance cost of the plant per capacity in $/kW.

This will not be used if the All Inclusive O&M is available. If this is zero, then this term will zero out and processing will continue.

**Variable O&M** US$/mW h Variable operations and maintenance cost of the plant per capacity in $/kW.

This will not be used if the All Inclusive O&M is available. If this is zero, then this term will zero out and processing will continue.

**O&M** US$/kW If the data point does not have any operational costs at all, then the same approach will be used with the Program Estimates; namely, for the given technology, if there is a program estimate for AllInclusive O&M, that will be used. If not, the program estimates for the technology fixed and variable O&M will be used. If none of these exist, then the LCOE will be set to zero.

**Fuel Price** US$/M MBtu fuel cost of the plant in ($/mmBTU)

The cost depends on the type of fuel used:

- **Bio Gas**: $4.40
- **Coal**: $2.34
- **Oil, Gas, or Steam**: $4.40
Some geothermal applications have the potential for rapid response, but are not used as such because it would not be feasible (Kaplan, 2008).

The ability to respond to demand of the hybrid technologies is always better than a single renewable energy this is the main reason of using hybrid energies.

**Efficiency (%)**: (Alexandru Maxim (2014), IEA 2011a)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal</td>
<td>15</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>40</td>
</tr>
<tr>
<td>Biomass</td>
<td>35</td>
</tr>
<tr>
<td>Wind</td>
<td>100</td>
</tr>
<tr>
<td>Solar PV</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat Rate</th>
<th>US$/M MBtu</th>
<th>The efficiency of the power plant in converting fuel into electricity</th>
<th>If the value is not defined in the data, zero is used.</th>
<th>HeatRate</th>
</tr>
</thead>
</table>
**Land use (m²/MWh):** Alexandru Maxim (2014), Bertani (2005), Fthenakis and Kim (2009).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal</td>
<td>0.74</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>0.46</td>
</tr>
<tr>
<td>Biomass</td>
<td>12.65</td>
</tr>
<tr>
<td>Wind</td>
<td>1.75</td>
</tr>
<tr>
<td>Solar pv</td>
<td>0.33</td>
</tr>
</tbody>
</table>

**Safety and human health costs (£/MWh):** (Alexandru Maxim (2014), Kagel and Gawell, 2005, Breeze, 2005.)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal</td>
<td>0 - 0</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>0.438 - 0.438</td>
</tr>
<tr>
<td>Biomass</td>
<td>0.170 - 4.250</td>
</tr>
<tr>
<td>Wind</td>
<td>0.034 - 0.168</td>
</tr>
<tr>
<td>Solar pv</td>
<td>0.438 - 0.438</td>
</tr>
</tbody>
</table>

We calculated the average values: (min+max)/2

**Social acceptability:** (Alexandru Maxim (2014), Bronfman et al., 2012)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal</td>
<td>Medium</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>High</td>
</tr>
<tr>
<td>Biomass</td>
<td>Medium</td>
</tr>
<tr>
<td>Wind</td>
<td>High</td>
</tr>
<tr>
<td>Solar pv</td>
<td>High</td>
</tr>
</tbody>
</table>

In this work, social acceptability of a hybrid technology was taken to be the worst between the two technologies.
Job creation (job-years/MWh): (Alexandru maxim (2014), Wei et al. (2010). )

<table>
<thead>
<tr>
<th>Technology</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal</td>
<td>0.25</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>0.23</td>
</tr>
<tr>
<td>Biomass</td>
<td>0.21</td>
</tr>
<tr>
<td>Wind</td>
<td>0.87</td>
</tr>
<tr>
<td>Solar pv</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Biomass power:

**Biomass potential (kg)** = (Number of palm in each city \( \times \) waste of 1 palm) + (population \( \times \) waste of one person)

Conversion from kg to TOE 1kg=0.0007 TOE