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SELECTION OF RENEWABLE ENERGY RESOURCES FOR SUSTAINABLE DEVELOPMENT WITH AHP TOOL FOR OFF-GRID PROJECT:CASE OF GHANA

Technology and Communication

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ABSTRACT

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In this thesis, renewable energy alternatives are studied in order to address the lack of electricity access in rural areas in Ghana. Three renewable energy sources were selected: solar, biomass and wind energies. The objectives of the study are firstly to establish the criteria impacting the selection of renewable energy source for off-grid and on-grid; secondly, to identify the best suitable renewable energy source for an off-grid project in Ghana.

The analytic hierarchy process (AHP) was used in this study in order to determine the suitable renewable energy source for rural electrification.

The result obtained using the AHP tool present solar energy as the best renewable energy source for an off-grid project in Ghana with 42.35% followed by biomass with 40.77% and wind energy with 16.88%.

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LIST OF ABBREVIATIONS

CF: capacity factor

Tech. Maturity: technology maturity

Expert HR: expert human resource

N. Energy security: national Energy security

N. Economic benefit: national Economic benefit

RE: Renewable Energy

RES: Renewable Energy sources

RETs: Renewable Energy technologies

MDGs: Millennium Development Goals -

MCDA: Multiple Criteria Decision Analysis

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1 INTRODUCTION

The economic development of a country depends on the ability of its population to access energy and fulfills its energy needs-based. Ghana is a country of West African with a population of 25 million (World Bank, 2014)**.** 10% of the urban population and 48% of the rural population do not have access to electricity. The access to electricity in Ghana is conditioned by the connection to the grid. However, only the urban area benefits for the grid connection with the grid covering more than 90% of the urban area (International Energy Agency, 2013). Hence, there is a need to develop and promote the usage of renewable energy sources in order to provide energy to those in the rural area who do not have access to grid. The energy access has worsened even for the urban community (Bosiako, 2011). This is due to recurrent power shortage. As mention in IRENA article, "Renewable technologies are now the most economical solution for off-grid electrification and grid extension in most areas, as well as for centralized grid supply in locations with good resources (IRENA, 2012). Renewable energy sources are the only solution to the rural community to get an access to electricity and support to electricity generation for the urban cities; provided that efficient, affordable and cost efficient technologies are selected. RES sources can be utilize to support the electricity production; or as self-powering sources for the remote communities and villages that do not have access to the grid. RES include solar, wind, biomass and geothermal energy.

The purpose of this paper is to provide a guideline in the selection of RES (mainly solar, wind and biomass) for electricity production using the Analytic Hierarchical Process (AHP) for an off-grid project. Previous literatures in the utilization of AHP will be used as a guide.

1.1 Research Objectives

This study intends:

- To establish the criteria impacting the selection of RES for off and on-grid project in Ghana.
- To identify the best suitable RES for an off-grid project in Ghana.

1.2 Research Questions:

This study will answer the following questions:

- What are the criteria and sub-criteria that can be considered in the selection of REs in Ghana for an on and off-grid project?
- What RES can best contribute to the development of rural communities in Ghana?

1.3 Outline of the Study

The literature review will be discussed in Chapter 2 of this study. In Chapter 2, the various RES and their potentiality will be analyzed and established. In Chapter 3, the importance of adopting a scientific approach in the selection of renewable energy sources will be established and the scientific method use introduced. The previous criteria and sub-criteria used in precedent RES selection will be presented in the same Chapter. Chapter 4 of this study presents the sub-criteria that should be considered when selecting an off-grid project as well as an on grid-project. Chapter 5 describes the methodology use in the study. The result of the data gathering as well as its analysis will be presented in Chapter 6. Chapter 7 discussed the result obtain in the section 6. Depending on the result obtained in this paper, the best and suitable RETs will be decide in the conclusion.

1.4 Limitations

The major limitation of this study is the lack of resource. Nevertheless, the quality of experts consulted in this study make its result irrefutable and their contribution fairly reflects the selection of RES for off-grid project and also an attempt to solve the rural electrification dilemma in Ghana.

Another limitation was the size of the sample. Through the study of literature and personal knowledge of the situation in Ghana, it was concluded that a precise approach to the RES selection needed to be divided into two different types of projects: on-grid and off-grid projects; each projects having its own sub-criteria. Due to time limit, 4 criteria were chosen instead of 6 criteria and 8 sub-criteria for an off-grid project. Only criteria and sub-criteria were retained that are critical for RES selection although all the criteria and sub-criteria are important.

Despite the limitations, this study would provide valuable and practical information for the selection of RES for sustainable development in Ghana for off-grid project.

The next chapter present the literature review related to the availability of RES in Ghana.

2 AVAILABILITY OF RES IN GHANA

The primary source of electricity has been hydropower (50 %) and natural gas resources (50%) of the total electricity production. See Table 1 and Figure 1(VOLTA RIVER AUTHORITY, 2014).

Table 1. Installed and Effective Generation Capacity (VRA Power Generation: Facts & Figures)

Plants	Installed Capacity (MW)	Effective Capacity (MW)	Type	Fuel Type
Akosombo Hydro Station	1,02	1001	Hydro	Water
Kpong Hydro Station	160	120	Hydro	Water
Bui Hydro Dam	400	133	Hydro	Water
Takoradi Power Company (TAPCO) (T1)	330	330	Thermal	LCO/Gas
Takoradi International Company (TICO) (T2)	220	220	Thermal	LCO/Gas
Takoradi Thermal Plant (T3)	132	132	Thermal	LCO/Gas
Tema Thermal 1 Power Plant (TT1PP)	110	110	Thermal	LCO/Gas
Tema Thermal 2 Power Plant (TT2PP)	50	50	Thermal	DFO/Gas
Mines Reserve Plant (MRP)	80	80	Thermal	DFO
Sunon Asogli	200	200	Thermal	Gas
CENIT	110	110	Thermal	LCO/Gas
Navrongo Solar Farm	2	2	Renewable	Solar
Total	2,814 MW	2,492 MW		

	TOTAL	
TYPES	INSTALLED CAPACITY	EFFECTIVE CAPACITY
HYDRO	1580 MW	1254 MW
THERMAL	1232 MW	1232 MW
RENEWABLE ENERGY	2 MW	2 MW

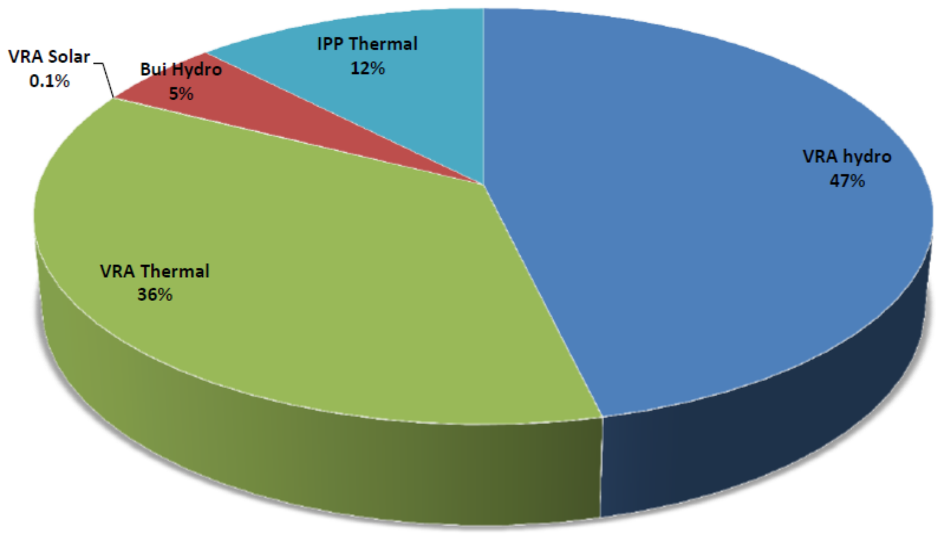


Figure 1; Ghana's effective installed generation sources as at March, 2014

(Ghana’s Power Outlook 2014)

Around 28% of Ghana population does not have access to grid; making their daily life a struggle despite the great energy potential of the country and the MDGs (Obeng, et al., 2009). The electrification rate being 72%, the urban electrification rate is 90% and the rural rate electrification is 52%. See Table 2(International Energy Agency, 2013).

Table 2. Electricity access in Africa

SOURCE: IEA, World Energy Outlook 2013

Table 2: Electricity access in 2011 - Africa

Region	Population without electricity (millions)	Electrification rate (%)	Urban electrification rate (%)	Rural electrification rate (%)
Sub-Saharan Africa	599	31,8	55,2	18,3
Angola	*12*	*38*	*58*	*8*
Benin	*7*	*28*	*55*	*6*
Botswana	*1*	*46*	*68*	*10*
Burkina Faso	*14*	*13*	*39*	*4*
Cameroon	*9*	*54*	*88*	*17*
Congo, Rep	*3*	*38*	*54*	*10*
Cote d'Ivoire	*8*	*59*	*85*	*32*
DR of Congo	*62*	*9*	*26*	*0*
Eritrea	*4*	*32*	*86*	*17*
Ethiopia	*65*	*23*	*85*	*11*
Gabon	*1*	*60*	*64*	*34*
Ghana	7	72	90	52
Kenya	*34*	*19*	*58*	*7*
Lesotho	*2*	*19*	*45*	*9*
Madagascar	*18*	*14*	*62*	*-9*
Malawi	*14*	*7*	*37*	*1*
Mauritius	*0*	*99*	*100*	*99*
Mozambique	*19*	*20*	*55*	*5*
Namibia	*1*	*60*	*83*	*46*
Nigeria	*85*	*48*	*35*	*61*
Senegal	*6*	*57*	*88*	*33*
South Africa	*8*	*85*	*96*	*67*
Sudan	*25*	*29*	*57*	*14*
Tanzania	*39*	*15*	*46*	*4*
Togo	*5*	*27*	*35*	*21*
Uganda	*30*	*15*	*55*	*7*
Zambia	*11*	*22*	*51*	*3*
Zimbabwe	*8*	*37*	*83*	*8*
Other sub-Saharan Africa	*105*	*13*	*34*	*4*
North Africa	1	99,4	100,0	98,7
Algeria	*0*	*99*	*100*	*98*
Egypt	*0*	*100*	*100*	*99*
Libya	*0*	*100*	*100*	*99*
Morocco	*0*	*99*	*100*	*97*
Tunisia	*0*	*100*	*100*	*99*
Africa	600	42,6	65,2	27,8

In this section, the potential of renewable energy sources for Ghana is presented. Three RES were selected: solar energy, wind energy and biomass.

2.1 Solar Energy

Solar energy is obtained by using the sun radiation as fuel to generate heat or electricity. Solar technologies are divided into two categories: passive and active. Passive solar produces heat for structures. Active solar technologies produce electricity from: photovoltaic or solar cells and concentrating solar power plants.

By its location within the tropics, Ghana receives high levels of daily solar radiation. Table 3 shows the daily solar radiation in various cities in Ghana. The estimated solar radiation levels are between 4 –6 kWh/m2 during peak hours (Schillings, et al., 2004)

Table 3. Solar radiation in Ghana (UNEP's SWERA)

SYNOPTIC STATION	GROUND (KWH\M^2-DAY)	SATELLITE (WH\M^{2}DAY)	% ERROR
KUMASI	4.633	5.155	2.30
ACCRA	5.000	5.180	4.70
NAVRONGO	5.505	5.765	0.80
ABETIFI	5.190	5.192	15.9
AKUSE	4.814	5.580	3.70
WA	5.520	5.729	13.3
AKIM ODA	4.567	5.177	1.50
WENCHI	5.020	5.093	2.00
KETE KRACHI	5.122	5.345	1.30
TAKORADI	5.011	5.200	3.80
YENDI	5.370	5.632	4.80

The study conducted by UNEP's SWERA (Solar and Wind Energy Resource Assessment) shows that the northern part of Ghana receives good solar radiation in the range of 3.5-4.5 kWh/m2/day (Figure 2). At this rate, the solar energy potential is enormous. Solar energy could be utilized to produce electricity to this part of the country.

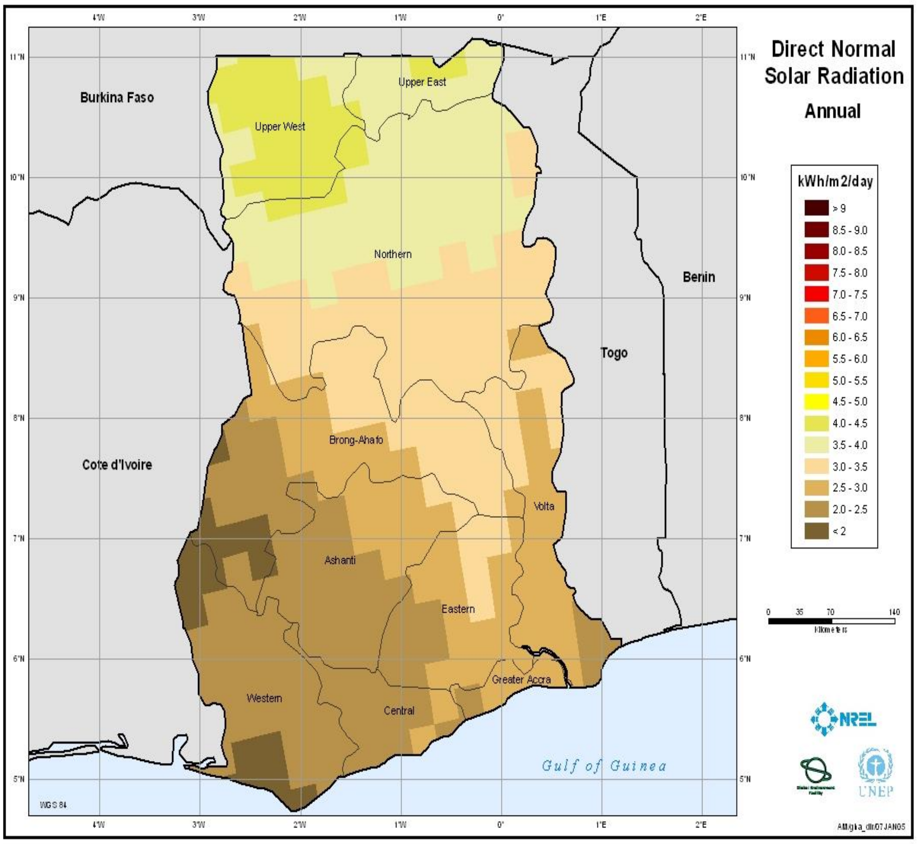


Figure 2; solar map of Ghana developed by NREL and USAID (NREL 2010)

One thousand two hundred and eighty-six (1,286) solar systems have been installed in 330 communities in 42 districts in Ghana (Communications Unit, MoEP, 2013).. The first solar on grid power plant was inaugurated in the Upper East region. The capacity of the Navrongo power plant is 2 MW. Adding to that, 14 MW solar plants are planned to be built (Volta River Authority, 2013).

These studies establish the fact that Ghana has enough solar energy potential needed to generate electricity through the use of solar panels or CSP. The wind potentiality will be presented in the next paragraphs.

2.2 Wind Energy

Wind has been used previously to power water pumping windmills, grinding grains, sailings ships. Nowadays, wind is mainly use in order to produce electricity. In this section, Ghana wind potentiality will be reviewed. The total estimated wind installed energy is 318 105 MW. (See Figure 3)

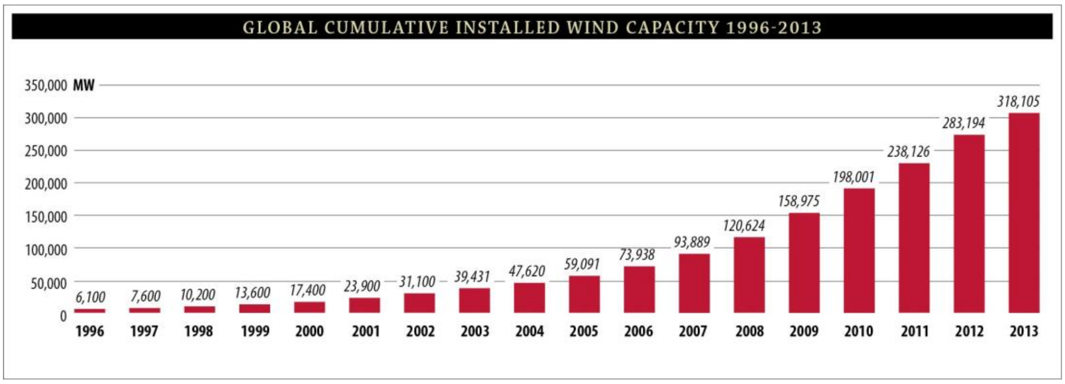


Figure 3. Global cumulative installed wind capacity. (GWEC 2012)

Wind energy is the production of energy using turbines sets on motion by the direction of wind. Wind energy business has known a growing capacity over the past years and according to the GWEO scenarios, its future is even brighter for Africa. With an average installed capacity of 993 MW in Africa and average installed capacity across Egypt of 550 MW, Morocco of 291 MW, Tunisia of 114 MW and Cape Verde of 24 MW, GWEO predicts an actual growth of 47 TWh by the year 2020. This would then grow by 4,000 - 6,000 MW every year up to 2030, when just under 68 GW would be installed, producing over 178 TWh of clean electricity for Africa (GLOBAL Wind EnErGy Council, 2012). Wind technology has experienced a tremendous growth in size but also in efficiency. The first wind turbines were 17m long while nowadays they are now 100 m long. (See Figure 4)

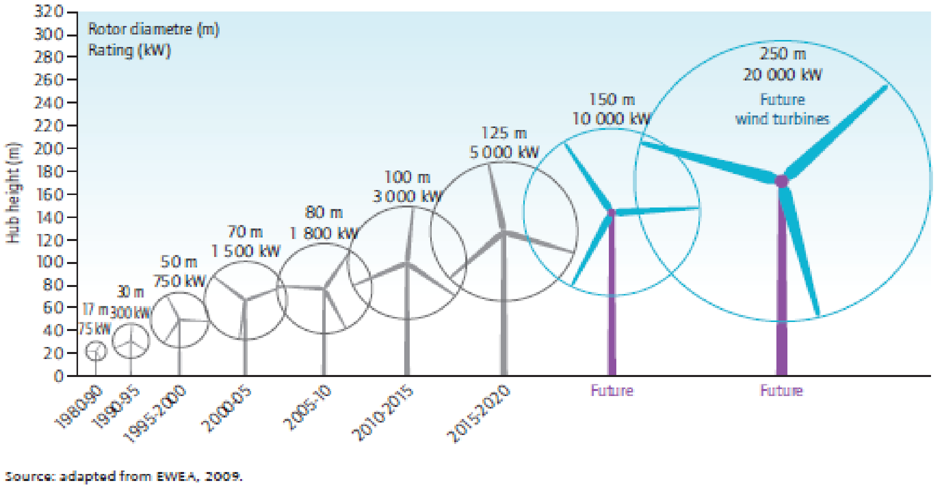


Figure 4. Growth in size of wind turbines (source EWEA)

As shown in NREL maps, the strongest wind regime occurs along the Ghana/Togo border: 9.0-9.9 meters per second; wind speed that can yield a wind power density of 600-800 Watt/m^2 in the mountains over an area of about 300-400 square kilometers. The total wind energy potential of this area is estimated at around 300 MW capacities or 800 GWh electricity. Over a large area along the coast, high winds (6.2-7.1 meters per second at the height of 50 m) are also present - total potential there is around 3000 MW capacity or 7,300 GWh. (See Figure 5).

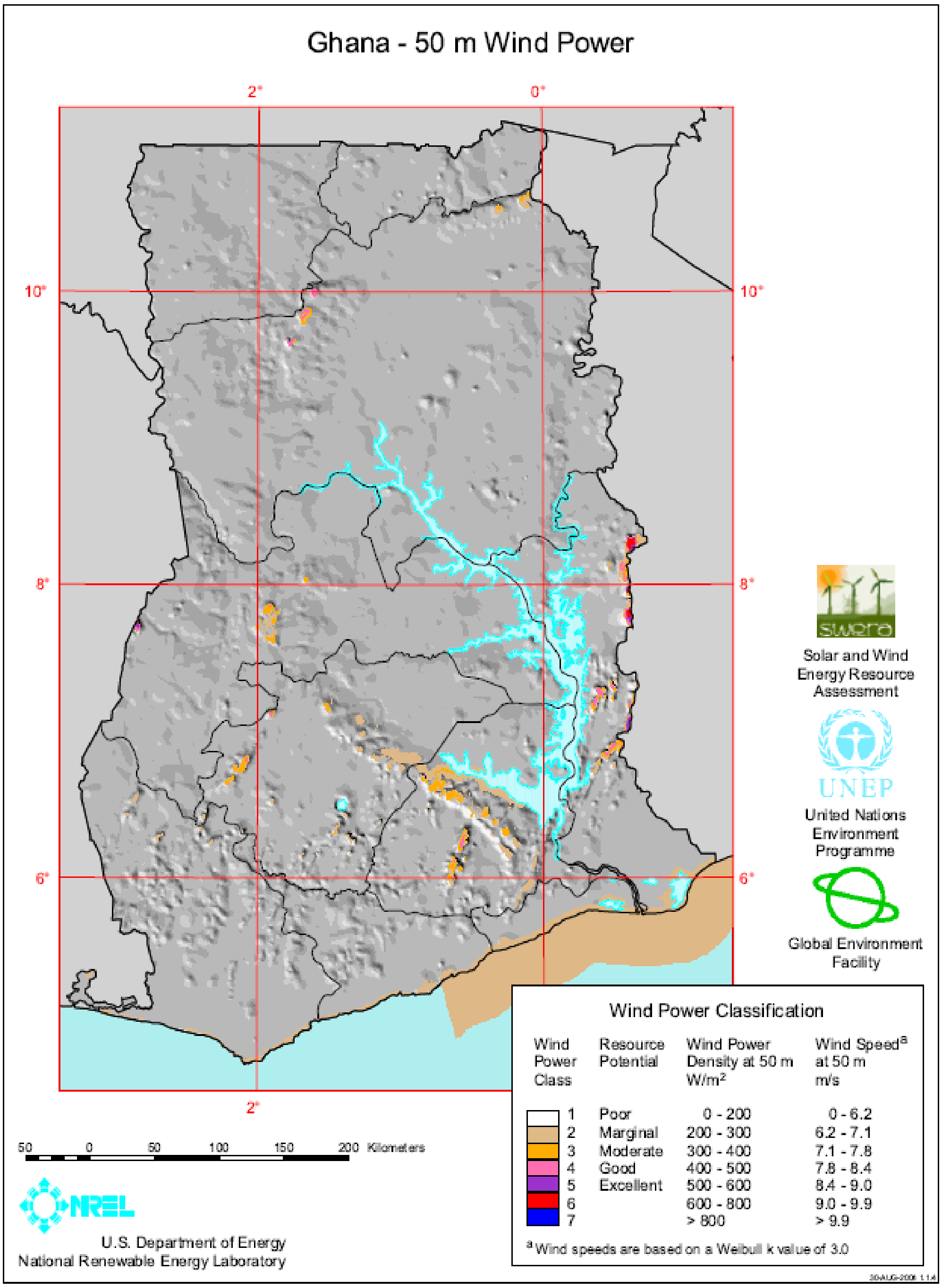


Figure 5. Wind map of Ghana developed by NREL and USAID (NREL 2010)

The Ghana Wind Energy Resource Mapping report estimates that there are 413 km^2 of areas with good-to-excellent wind resource potential in Ghana, and these windy areas represent 0.2% of Ghana's total land area. Using a conservative assumption of 5 MW per km^2, this windy area could support more than 2,000 MW of potential installed wind capacity (See Table 4).

Table 4. Wind energy potential (Good-to-Excellent Wind Resource at 50 m)

Wind Resource	Wind Class	Wind Power At 50 W/M^2	Wind Speed At 50m M/S	Total Area Km^2	Percent Windy Land	Wind Resource
Good	**4**	**400–500**	**7.0–7.5**	**268**	**0.1**	**1340**
Excellent	**5**	**500–600**	**7.5–8.0**	**82**	**<0.1**	**410**
Excellent	**6**	**600–800**	**8.0–8.8**	**63**	**<0.1**	**315**
Total				**413**	**0.2**	**2065**

If additional areas with moderate wind resource potential are considered, the estimated total windy area increases to 1,128 km^2. This amount of windy area represents 0.5% of Ghana's total area and could support more than 5,600 MW of installed capacity (See Table 5). (OpenEI, ei pvm)

Table 5. Wind energy potential (Moderate-to-Excellent Wind Resource at 50 m)

Wind Resource Utility Scale	Wind Class	Wind Power at 50 m W/m^2	Wind Speed at 50 m/s	Total Area km^2	Percent Windy Land	Total Capacity Installed MW
Moderate	**3**	**300 – 400**	**6.4 – 7.0**	**715**	**0.3**	**3,575**
Good	**4**	**400 – 500**	**7.0 – 7.5**	**268**	**0.1**	**1,34**
Excellent	**5**	**500 – 600**	**7.5 – 8.0**	**82**	**<0.1**	**410**
Excellent	**6**	**600 – 800**	**8.0 – 8.8**	**63**	**<0.1**	**315**
Total				**1,128**	**0.5**	**5,64**

The report elaborated by the VRA shows that the wind potential across the 10 regions of the country (Table 6). The wind potential at the Ghana/Togo border (Volta Region) and along the coast of the Gulf of Guinea is suitable for grid connected large wind farms while the scattered wind potential can be exploited through stand-alone wind turbines (OpenEI, ei pvm). VRA is committed to build a 150 MW wind power (Volta River Authority, 2013).

Table 6. Wind measurement by regions

Province	Class 3 (Km^2)	Class 4 (Km^2)	Class 5 (Km^2)	Class 6 (Km^2)	Good To Excellent Potential (MW)	Moderate To Ecxellent Potential (MW)
Ashanti	93	11	0	0	55	520
Brong-Ahafo	83	17	16	2	175	590
Central	0	0	0	0	0	0
Eastern	285	26	0	0	130	1550
Greater Accra	0	0	0	0	0	0
Northern	73	53	0	0	265	630
Upper East	0	0	0	0	0	0
Upper West	0	0	0	61	0	0
Volta	181	161	66	0	1440	2345
Western	0	0	0	0	0	0
Total	715	268	82	63	2065	5640

A detailed wind assessment was conducted by the Energy commission. According to this assessment; the sites with high wind potentials are located along the east coastlines (See Table 7).

Table 7. Wind Measurement along the coast areas in Ghana (Energy Commission ,Ghana)

Site	Latitude	Longitude	Altitude	Height	Annual Mean Speed At 12m(m/s)	Predicted Wind Speed At 50m(m/s)
Adafoah	5,79	0.55	0	12	5,3	0
Aplaku	5,32	0.20	50	12	5,2	6,92
Asemkow	5,21	3,27	10	12	3,7	5,16
Kpone	5,68	0.07	96	12	4,9	7,18
Lolonya	5,79	0.44	40	12	5,4	7,15
Pute	5,79	0.52	3	12	5,5	7,37
Tema	5,62	0.07	50	12	5	6,66
Warabeba	5,22	0.35	50	12	3,9	5,38
Anloga	5,47	0.55	-7	20	5,4	6,8
Amedzofe	5,5	0.25	740	20	3,9	5.00
Kue	5,3	0.35	327	30	2,9	3,4
Nkwanta	5,15	0.30	295	30	3,5	4.00

This study establishes the fact that wind energy can actually be exploited along the Togo border and in some specific areas as shown in the map.

2.3 Biomass

Biomass is the transformation of organic resources into a variety of product such as heat or electricity. Several technological processes are used to transform organic resources into a useful product. Some these processes are: combustion, co-firing. The process of transformation is illustrated in Figure 6. (Simona , et al., 2012)

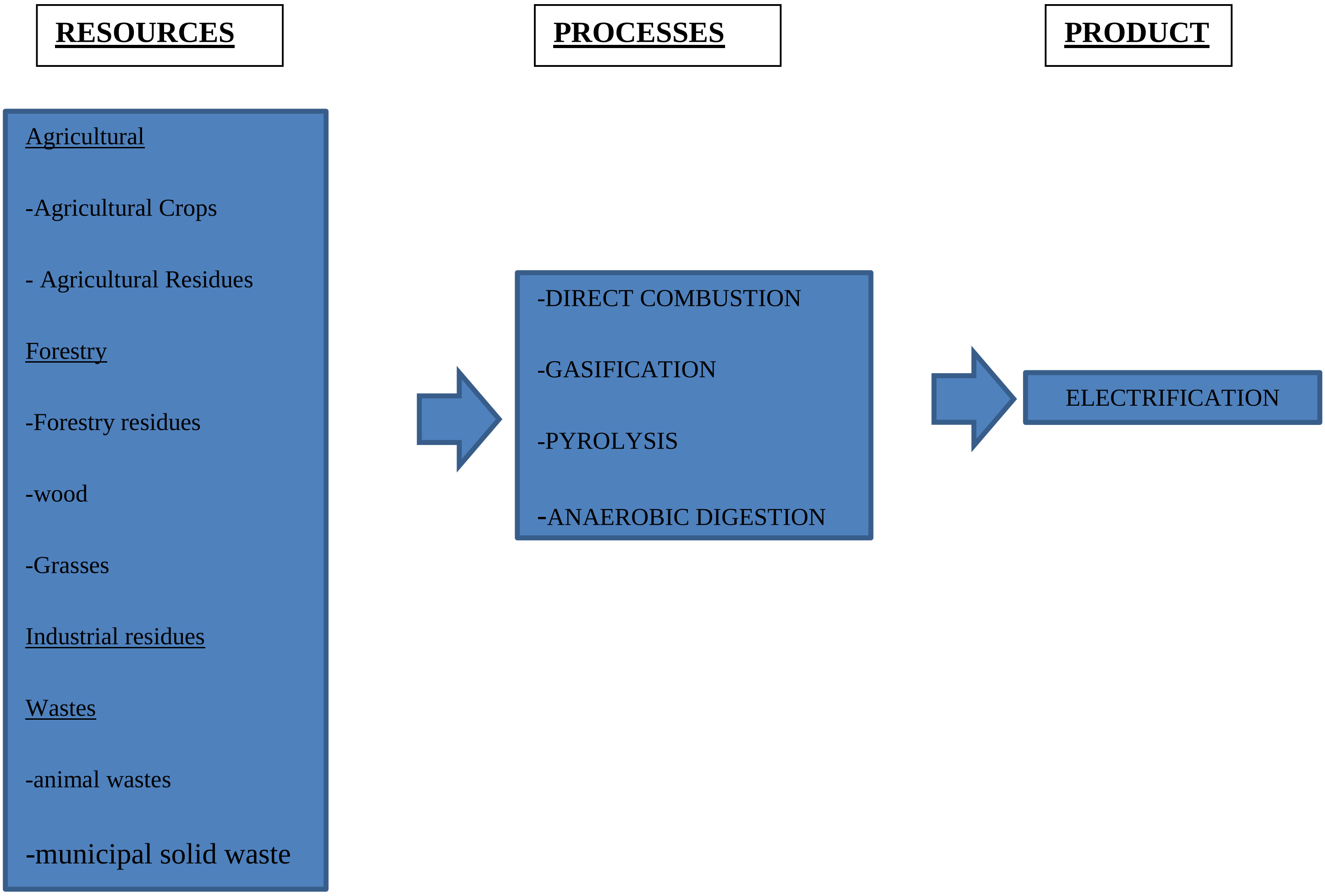


Figure 6. Electricity production through Biomass (Simona , et al., 2012)

According to Financial International Energy Agency, biomass energy is the most widely used form of renewable energy worldwide, accounting for 10% of total energy consumption. And out of this, two-third is used for cooking and heating in the developing countries. In 2009, about 13 % of biomass used was consumed for heat and power generation, while the industrial sector consumed 15% and transportation 4%. The global consumption of biofuels in transportation equaled 2 % of the total transport sector (Schill, 2013). The use of biomass in Ghana mainly refers to the utilization of a certain number of feedstock (Figure 7). The available biomass feedstock in Ghana are: agricultural resource, forestry resource, urban and other wastes. (Kampb, et al., 2014), (Mohammeda, et al., 2013):

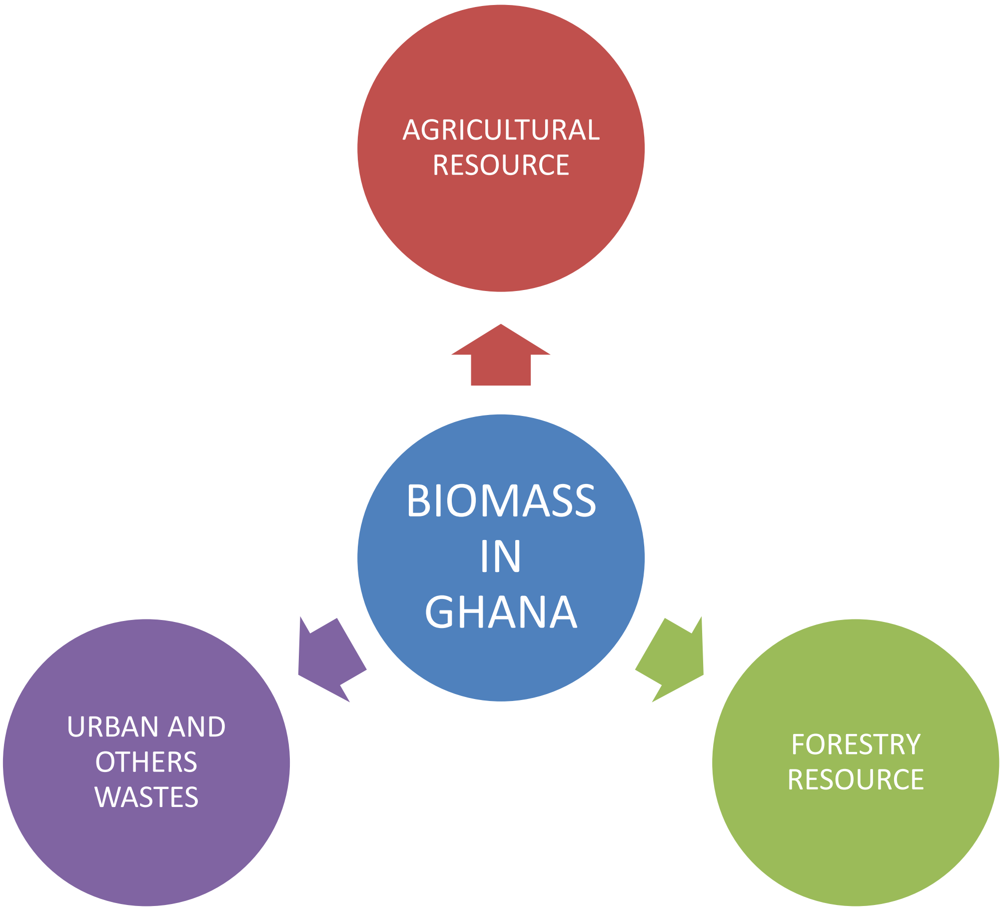


Figure 7. Biomass resources available in Ghana

Agricultural resource

The utilization of agricultural resource refers to the use of agricultural crops and the agricultural residues. The utilization of agricultural crops implies the use of: sugarcane, sweet sorghum, maize, cassava, oil palm, coconut, sunflower, soy bean and jatropha, etc… Table 8 illustrates the production of major agricultural crops.

Table 8.Production of major crops in Ghana 2008 (Mohammeda, et al., 2013)

PRODUCT	PRODUCTION (1000 tonnes)	YIELD OF CROP (Hg/ha)	AREA HARVEST-ED (ha)
Sorghum	350	10294	340000
Sugarcane	145	2544385	5700
Maize	1100	104615	750000
Rice	242	20166	120000
Cocoa beans	700	4000	1750000
Coffee, green	n.a	1650	10000
Cassava	9650	120625	800000
Seed cotton	2	8000	25000
Soya beans	50000	n.a	n.a
Coconuts	316	56936	55500
Oil palm nut	1900	6333	300000
Ground nut	4289	9317	460000
Jatropha Curas	n.a	n.a	1534
Sunflower	n.a	n.a	n.a
Grasses	n.a	n.a	n.a
Algae	n.a	n.a	n.a

Agricultural residues are of a wide variety of types, and the most appropriate energy conversion technologies and handling protocols vary from type to type. The most significant division is between those residues that are predominantly dry (such as straw) and those that are wet (such as animal slurry). Many agricultural crops and processes yield residues that can potentially be used for energy applications, in a number of ways originate from: arable crop residues such as straw or husks, animal manures and slurries, animal bedding such as poultry litter, most organic material from excess production or insufficient market, such as grass silage. In Ghana, crop residues include straw, stalk of cereals such as rice, maize/corn, sorghum, and millet, and cocoa pods. Agro-industrial by-products, on the other hand, are produced mainly after crop processing, and include cocoa husk, coconut shell and husk, rice husk, oil seed cakes, sugar cane bagasse, and oil palm empty fruit bunch see table 9 .(Mohammeda, et al., 2013), (Moses , et al., 2011)

Table 9**.** Production of different agricultural crops in 2008 and estimated potential of residues, calculated using residue to product ratio lower heating value (Moses , et al., 2011)

Crop	Production (×1000 tonnes)	Residues types	Residues to product ratio	Moisture content	Residues wet residues	Residues dry residues	Lower heating Values(MJ/Kg)	Residue energy potential /TJ)
Sorghum	350	Stalk	2.65	15	971.00	779.45	17.00	15.59
Millet	160	Stalk	3	15	480.00	408.00	15.51	7.44
Rice	242	Straw	1,5	15	363.00	308.00	15.56	0.58
Sugarcane	145	Bagasse	0.3	75	43.50	10.875	13.38	0.58
Coconut	316	Shell	0.6	10	189.6	170.64	10.61	2,01
Oil Palm Fruit	1900	EFB	0.25	60	4750	190.00	15.51	7.37
Coffee	165	Husk	2.1	15	346.50	294.525	12.56	0.04
Cocoa	700	Pod,Husk	1	15	700.00	595.00	15.48	10.84
Maize	1100	Stalk	1.5	15	1650.00	1402.50	15.48	25.76
Total					**4821.6**			**75.20**

Forestry resource

Forestry resource biomass is divided into two main types of feedstock: forest biomass and forest residue. Forest biomass is the proportion of forest in a country, while forest residue is defined as the biomass material remaining in forests that have been harvested. In Ghana, the forest biomass can become a source of energy. According to the FAO, in 2010, the forest occupied 23854 millions of ha (See table 10). The residues generated from the forest products industry can be grouped into two categories: logging residues, generated from logging activities and industrial by-products generated by wood processing firms during the manufacture of saw wood, plywood, and particleboard. In Ghana, A study conducted by Amoah and Becker on commercial logging efficiency in Ghana showed an average logging recovery of 75%. While, the total monthly average volume of residue (veneer core, trimmings and defective veneer and plywood) was 1617.979 m^3 (40.37%) and most mills in Ghana generate an average annual wood residue of 33.3%. (Kampb, et al., 2014)

Table 10. Land occupied by forest (Kampb, et al., 2014)

FRA 2010 categories	Area (1000 hectares)			
	1990	2000	2005	2010
Forest	**7448**	**6094**	**5517**	**4940**
Other wooded land	**0**	**0**	**0**	**0**
Other land	**15306**	**1660**	**17237**	**17814**
Inland water bodies	**1100**	**1100**	**1100**	**1100**
TOTAL	**23854**	**23854**	**23854**	**23854**

Urban wastes and other wastes

Urban wastes can be defined as being the waste generated by any activity in urban or peri-urban areas. This implies that urban waste is not only that generated in households, but also from commercial establishments and services, street sweeping, green areas and industry. Waste is usually generated by the following variety of sources: household, commercial establishment, institution, factories. In Ghana, urban wastes can be divided into four groups:

1) Municipal Solid waste (MSW): According to Kramer it is estimated that approximately 760,000 tons of MSW annually or approximately 2,000 tons per day is generated in Accra, the capital.

2) Food industry wastes: generated by the hotels, restaurant, fast food, etc…

3) Industrial wastewater/sewage sludge/bio-solids: Industrial wastewater treatment in Ghana is not common due to the location of most of the companies along the coast. However, some companies and abattoirs carry out wastewater treatment. They can be find in Kumasi, Tema Community Three, the University of Ghana Staff Village, and the Burma Camp, the Nsawam Maximum Security Prison, the Kwame Nkrumah University of Science and Technology, Kumasi, the La Palm Royal Beach Hotel, Golden Tulip, and the 37 Military Hospital in Accra. (Kampb, et al., 2014)

4) Animal wastes: The feeding of animals generates large amounts of manure. This manure from animal feeding operations can be a valuable resource. Manure is used in digesters (machines which decompose manure and capture the methane gas emitted) to produce electricity, and other useful by-products such as ethanol. In Ghana, the most domesticated livestock are cattle, pig, sheep and poultry. (Kampb, et al., 2014)

Table 11 shows the average biomass feedstock available per year. The values in this table establish the fact that there is enough biomass feedstock in Ghana in order to exploit Biomass energy. (Otu-Danquah, 2012)

Table 11. Biomass production per year (Otu-Danquah, 2012)

Types of feedstock	Availability per annum
Wood fuel supply	18 million tons /year
Municipal waste	2 million tons/year
Wood residue	2 million tons/year
Crop residue	13 million tons/year
Animal waste	11 million tons/year

The previous chapter establishes the fact that RES particularly wind, solar and biomass can be harnessed in Ghana due to their availability. A number of projects have been planned nationwide in order to enhance the production of electricity through the use of the use of RETs. The country situation despite the availability of the sources does not allow the utilization of all the sources in order to generate electricity for rural areas or off-grid communities, houses. There is therefore the need to utilize a tool capable of selecting appropriate RES for off-grid facilities taking into account all the factors impacting the selection.

The following chapter introduces the tool selected in this thesis in order to effectively select an efficient and appropriate tool for off-grid project in Ghana.

3 MULTI-CRITERIA DECISION ANALYSIS

The selection of RES for a country is a long term effect decision; therefore it is complex and tedious task. It necessitates the consideration of factors likely to impact the operations of the chosen RETs. Hence, a multi-criteria decision analysis selection based is needed. A multiple-criteria decision analysis (MCDA) is a research method that explicitly considers multiple criteria in decision-making environments. The MCDA method proceeds to the analysis of a problem base on the analysis of factors likely to impart the problem. Multiple MCDA methods have been implemented and developed in order to solve multi criteria problems. Among those method, the Analytical Hierarchal Process (AHP) is one of the outstanding and most MCDA method used in the energy field decision because any complex situation requiring structuring, measurement, and/or synthesis is a good candidate for AHP. In this chapter, the AHP method will be introduced as well as its utilization in the energy sector.

3.1 AHP

The analytic hierarchy process (AHP) is a systematic method for comparing a list of objectives or alternatives. It was developed by Thomas L. Saaty in the 1970s. The AHP derives ratio scales from paired comparison. The AHP process consists of:

- Clear definition of objective or goal
- Structuring elements into criteria, sub-criteria and alternatives
- Making a pair wise comparison of element in each group
- Calculating weighting and consistency ratio
- Evaluating the rating according to weight
- Obtaining the ranking of each alternatives

The AHP allows the decision maker to decompose the complexity of the decision into many small but related sub-problems in the form of a hierarchy. After being divided, the decision makers evaluate various elements by comparing them to one another. The comparison is made on 1-9 scale measurement (Table 12). The AHP has been used in variant problem-solving. Its decision has been scientifically approved. Generally, an expert is needed to establish the importance of the criteria and sub-criteria by pair-wising the comparison.

Table 12.Ranking

Numerical Rating	Verbal Judgement Of Preferences
9	Extremely Preferred / Important
8	Very Strongly To Extremely
6	Strongly To Very Strongly
5	Strongly Preferred / Important
4	Moderately To Strongly
3	Moderately Preferred / Important
2	Equally To Moderately
1	Equally Preferred / Important

The consistency of the decision has to be checked by determining the consistency index (CI) and the consistency ratio (CR). For finding the consistency index, CI, the formula used is:

$CI = (\lambda_{max} - n) / (n - 1)$, where: n is the size of the matrix λ_{max} the maximum eigenvalue.

The consistency ratio (CR) is obtained by:

$CR = \frac{CI}{RI}$ Where RI is the average random consistency (see Table 13). The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent; then the matrix has to be reviewed to obtain a consistent matrix.

Table 13. Average Random

SIZE OF MATRIX	RANDON CONSISTENCY
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

3.2 AHP Energy Usage

The AHP is the most frequently used MCDA method used in the world in decision taking currently. The success of AHP relies on the appropriate judgment from the expert in selecting the AHP approach. The AHP is needed in certain problem environments such as problems involving: choice, prioritization or evaluation, resource allocation, benchmarking, quality management, public decision, healthcare and strategic planning.

In the energy sector, the AHP has been recently introduced and has gradually become the MCDA method by excellence in energy decision making process. It has been used in waste management, selection of RETs, greenhouse gases emission, site selection, comparison of various plant for electricity generation, energy conservation policy, CO_2 emissions, evaluation of energy resources, to find a suitable financing scheme for renewable projects, evaluating space heating options, energy policy formulation, energy planning, power plant selection, power plant location selection, energy resource allocation, integrated resource planning, energy exploitation, controlling greenhouse gas (GHG) emissions, and developing energy management systems.

3.3 Criteria and Sub-criteria Used

As mention before, the AHP proceeds to the selection of RES based on the analysis of criteria, sub-criteria and alternatives. In this study, the alternatives are: solar, wind and biomass power. Table 14 illustrates the previous criteria selected and how often they have been used in precedent RES selection studies during the past five years. It has been observed than five criteria have been identified as factors likely to impact the selection of RETs for a country; they are: political, economic, environmental, social and technological. These studies have been carried out in Turkey, Malaysia, Pakistan and Iran. According to the World Bank, these countries are developing countries (World Bank, 2013). Ghana being a developing country, it is thought holistic approach should consider the same criteria and sub-criteria in the selection of RES for Ghana.

Table 14: The previous criteria selected in RES

TECHNICAL	ECONOMICAL	ENVIRONMENTAL	SOCIAL	POLITICAL	COUNTRY	INCOME LEVEL	COUNTRY CLAS-SIFICATION	REFERENCES
X	X	X	X		TURKEY (ISTANBUL)	UPPER MIDDLE	DEVELOPING	(Tolga & Cengiz , 2010)
X	X	X	X	X	TURKEY	UPPER MIDDLE	DEVELOPING	(Cengiz & Ihsan, 2010)
X	X	X	X	X	PAKISTAN	LOWER MIDDLE	DEVELOPING	(Muhammad & Tugrul , 2011)
X	X	X	X	X	TURKEY	UPPER MIDDLE	DEVELOPING	(Demirtas, 2013)
X	X	X	X		MALAYSIA	UPPER MIDDLE	DEVELOPING	(Salman & Razman , 2013)
X	X	X	X	X	IRAN(YAZD)	UPPER MIDDLE	DEVELOPING	(Arash , et al., 2012)
					GHANA	LOWER MIDDLE	DEVELOPING	

Table 15 represents the criteria, sub-criteria selected in previous studies as well as their definitions. It also indicates when a sub-criterion is considered favorable for the selection. These were the criteria used in the case of Pakistan (Muhammad & Tugrul , 2011).

Table 15: criteria, sub-criteria selected in precedents studies (Muhammad & Tugrul , 2011)

CRITERIA	SUB-CRITERIA	DESCRIPTION
ECONOMICAL	• **R&D cost**	**Expenses occurred on the research and development of a technology alternative.** ***Alternative that has less R&D cost is considered better***
	• **Capital cost**	**Capital cost consists of total expenditure occurred in establishing a power plant including the equipment, labor, installation, infrastructure and commissioning cost.** ***Alternative that has less capital cost is considered better***
	• **O&M cost**	**Operations and maintenance cost includes the plant running cost including salaries of the employees, cost of the parts/spares required for scheduled maintenance purposes etc.** ***Alternative that has less O&M cost is considered better***
	• **Economic value/ viability**	**Economic viability of the power plant in the long run, it can be accessed by using NPV or payback period method.** ***Alternative that has less payback period is considered better***
	• **Electricity cost**	**Expected cost of the electricity generated by power plant.** ***Alternative that can generate electricity at a lower cost is considered better***

Table15**:** Criteria, sub-criteria selected in precedents studies (continued)

CRITERIA	SUB-CRITERIA	DESCRIPTION
TECHNICAL	• **Technology maturity**	**Technology maturity is indicated by how widespread technology is at regional, national and international levels. This measure also indicates that technology has reached the theoretical efficiency limit or still technology can be improved.** ***Mature technology alternative is considered better***
	• **Efficiency/capacity factor**	**Generally efficiency of a power plant refers to the ratio of the output energy to the input energy. Capacity factor is the ratio of the electrical energy produced during a time period to the energy that could have been produced at continuous full power operation during the same period. It also indicates that how much useful energy can be obtained from a source.** ***Alternative with higher capacity factor is considered better***
	• **Reliability**	**Reliability is defined as the ability of a system to perform as intended/designed under stated conditions. Reliability of a power plant is very critical** ***Alternative having higher reliability is considered better***
	• **Deployment time/ duration**	**Time required to set up power plant including installation, testing and commissioning time** ***Alternative with less deployment time is considered better***
	• **Expert human Resource**	**Expert man power available in the region/country to install, operate and maintain the equipment** ***Availability of more expert human resources for an alternative is considered better***
	• **Distribution grid availability**	**Availability and proximity of distribution grid for power transmission to the end user** ***Alternative that can easily transmit power through grid at lower cost is considered better***
	• **Resource availability**	**Availability of renewable resources (wind speed, solar radiations etc.) to generate energy** ***Alternative having more resource available is considered better***

Table15: Criteria, sub-criteria selected in precedents studies (continued)

CRITERIA	SUB-CRITERIA	DESCRIPTION
SOCIAL	**Social benefits**	**A social benefit represents the social progress in the local community and region by initiating a power project** ***Alternative that provides more social benefits to the society is considered better***
	Social acceptance	**Public opinion toward a type of power plant represents the social acceptance** ***Alternative that has favorable opinion in society is considered better***
	Job creation	**Energy projects generate employment opportunities especially for the local communities.**
POLITICAL	**National energy security**	**A country can enhance the energy security by utilizing indigenous renewable energy resources and reduce dependency on the foreign energy resources.** ***Alternative that would diversify the energy contribution is considered better***
	National economic benefits	**Benefits to national economy by utilizing indigenous renewable energy resources of the country.**

Due to the energy situation in Ghana, some sub-criteria need to be added to those already existing in table 15**.** Those sub-criteria are site location; infrastructure, flexibility and FIT. These sub-criteria are described in the following paragraphs:

Site location: The closeness of the site location to the raw material is very important. The farther the site is from the raw material, the more its logistics cost will increase and its production rate affected due to energy losses, delay. The closeness of the site to its raw material in the case of biomass will not be much affected if appropriate infrastructures allow a rapid transportation of the raw material. *Alternatives that are close to raw materials are considered better*

Infrastructure: Basic physical and organizational structures needed for the operation of a society, enterprise and facilities necessary for an economy to function, Infrastructure represents one of the key sub-criterion to consider in the selection of RES in developing countries. This is due to the high impending cost of the related logistic, energy production when the infrastructures are missing or not appropriate to the desired RES (A, et al., 2011). These infrastructures are roads, water…etc. Due to the importance of the transport infrastructure, infrastructure must be considered as criterion in this thesis. *Alternatives that are close to infrastructures and that does not depend heavily on infrastructure are considered better.*

Flexibility in use: RES technologies that do not require a high level of education to be operated or serviced is suitable. This is important in a developing country due to the lack of expertise and especially in rural areas. *Alternatives that are can be easily operated and services are considered better.*

Feed in tariff: A feed-in tariff is a policy designed to accelerate investment in renewable energy technologies. A FIT is a system in which the government mandates that utilities enter into long-term contracts with generators at specified rates; typically well above the retail price of electricity. FITs are needed when dealing with on-grid connection. *Alternatives that have high FITs are considered better*.

Tax incentives: Deduction, exclusion, or exemption from a tax liability, offered as an enticement to engage in a specified activity; tax incentives will allows investors to invest their money in the renewable energy sectors. This is a very important criterion for the investors due to the high investment cost in the renewable energy sector. Investors are reluctant to embark in countries where this policy is missing. *Alternatives that offer high tax incentives are considered better.*

Decentralization is defined as the possibility of each region to produce its own energy. Solution for rural communities, decentralization allows the region to rely on its own energy production, reduce the total cost; it also reduces the total CO_2 emission. *Alternatives that offer decentralization are considered better*

4 ON / OFF GRID SUB-CRITERIA

The sub-criteria needed in the selection of RES for a country depend heavily on the types of desired connection. An on-grid connection is usually complex and tedious. It requires a lot of formalities, more than an off-grid connection that provides electricity for a particular or an isolated town or community (this is the case of mini-grid connection). Therefore, sub-criteria to be considered when selecting RES for an off-grid project is likely to differ from those needed in the selection of RES for an on-grid project. Some of the sub-criteria may be common to both connection but the major differences rely on those sub-criteria that are not common to both connections. The following section establishes the various sub-criteria needed in differents types of connection. The criteria and sub criteria selected for the analysis are also presented

4.1 On-Grid Connection Sub-Criteria

An on-grid connection, usually links more plants together in order to provide a more flexible and reliable network for electricity generation. Hence, it requires particular factors that will facilitate its selections. Based on previous studies; those factors or sub-criteria are presented in Table 16 below.

Table 16: On-grid sub-criteria

ECONOMICAL	TECHNICAL	SOCIAL	ENVIRONMENTAL	POLITICAL	INFRASTRUCTURE
R & D Cost	T. Maturity	Social benefit	Land requirement	N. Energy security	TRANSPORT
Capital Cost	Efficiency/ CF	Job creation	Emission	N. Economic benefit	Distribution grid availability
O & M Cost	Expert human	Social acceptance	Site location		
E. viability	Resource availability		Stress on ecosystem		
FIT	Deployment time/ duration				
Tax incentives	Reliability				
	Decentralization				

4.2 Off-Grid Connection Sub-Criteria

An off-grid connection is used to provide a smaller community, houses, and small businesses with electricity. It can be a stand-alone system or mini-grid in case of small communities. A RES selection for an off-grid project will then slightly differs in its required factors from an off-grid connection. These factors are presented in Table17**.**

Table 17**:** Off-grid sub-criteria (Own-elaboration)

ECONOMICAL	TECHNICAL	SOCIAL	ENVIRONMENTAL	POLITICAL	INFRASTRUCTURE
R & D Cost	T. Maturity	Social benefit	Land requirement	N. Energy security	TRANSPORT
Capital Cost	Efficiency/ CF	Job creation	Emission*	N. Economic benefit	
O & M Cost	Reliability	Social acceptance	Site location		
E. viability	Deployment time		Stress on ecosystem*		
ELECTRICITY COST	Flexibility				
	Resource Available				

4.3 Case Of Ghana Off-Grid Project

A holistic selection of RES for an off-grid connection for Ghana would be based on Table 17**.** However, in this study, the selection of RES will be solely based on some criteria and sub-criteria. This is due to the factors cited in the limitation. It was decided that three main criteria likely to affect the selection of RES in Ghana are retained. The main criteria and their sub-criteria are presented below:

- Economical: electricity cost, capital cost, O & M cost.
- Technical: Reliability, efficiency and flexibility.
- Socio-environmental: land requirements, job creation
- Infrastructure: Transport

Economical:

- Electricity cost: Ghana being a developing country, priority for the users will be the affordability of the electricity produced. As mentioned in Table 15**,** the population is likely to choose alternatives with low electricity cost. It is to remark that in most cases in developing countries, the electricity price will be compared to the one in usage in the communities. In case of Ghana, the comparison will be against the diesel price. The population is likely to choose alternatives presenting less cost than the diesel fuel. The Figure 8 illustrates the average cost of electricity generation in OECD and non-OECD countries. There are no set values for off-grid electricity production cost in Ghana.

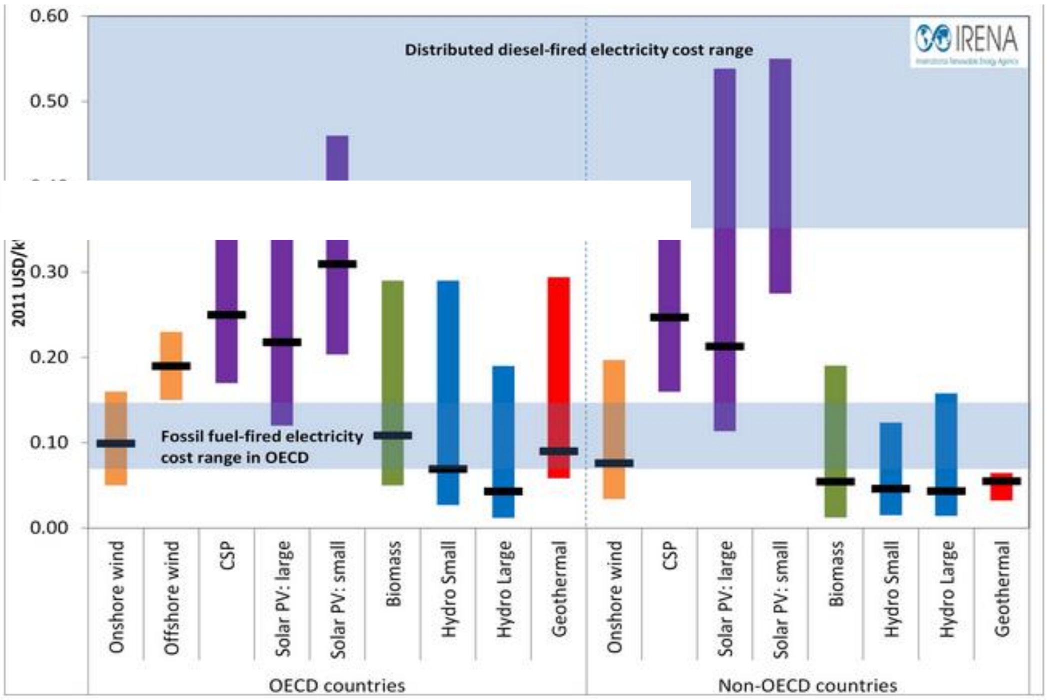


Figure 8. Cost of electricity produced((IRENA, 2012)

- Capital cost: Capital cost consists of total expenditure occurred in establishing a power plant including the equipment, labor, installation, infrastructure and commissioning cost. The capital cost of establishing a RET is almost the same everywhere depending on the desired capacity. The capital cost of each alternative is presented in Table 18.

- O & M cost: Operating expenses are associated with operating a facility (i.e., supervising and engineering expenses). Its values are also represented in Table 18 for each alternative. Those values are roughly to be viable for Ghana.

Table 18. Estimated Levelized Cost of Electricity (LCOE) for New Generation Resources, U.S. average levelized costs (2012 $/MWh) for plants entering service in 2019 (eia, s.d.)

Plant type	Capacity factor (%)	Levelized capital cost	Fixed O&M	Variable O&M (including fuel)	Transmission investment	Total system LCOE
Biomass	83	47,4	14,5	39,5	1,2	102,6
Wind	35	64,1	13	0	3,2	80,3
solar pv	25	114,5	11,4	0	4,1	130
solar thermal	20	195	42,1	0	6	243,1

Technical

- Reliability: As defined in Table 15**,** reliability is the ability of a system to perform as intended, designed under stated conditions. This is an important criterion in development countries;

- Efficiency: As defined in Table 15**,** efficiency is to the ratio of the output energy to the input energy.
- Flexibility in use: A technology requiring a high level of technology will not be appropriate for an off-grid project in Ghana. The system must be able to run without the expertise of high expert. It should not require high level of education in order to be service.

Socio-environmental:

- Land requirements: In Ghana, the acquisition of land is done with respect to laid down procedures. The various sites may be taken through private treaty transactions or by resorting to the states power of eminent domain. The average land intensity occupation is presented in Figure 10. As shown in Figure 10**,** biomass uses more area than others RES depending on the capacity.

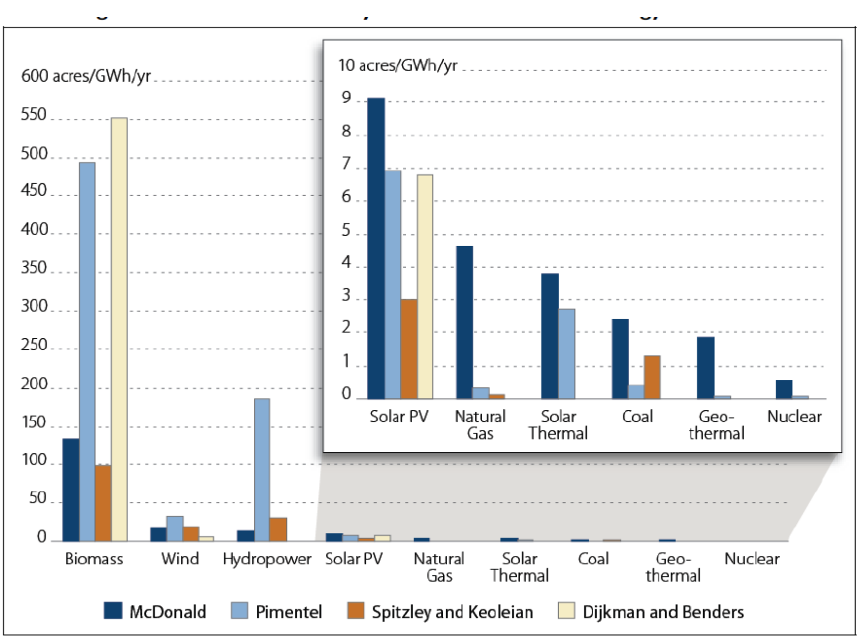


Figure 9: Land-Use Intensity for Various Forms of Energy Production based on different sources. (Brown & Whitney, 2011)

- Job creation: Ghana being a developing country, emphasis will not only be based on production of electricity; attention will also be focused on how much job creation the chosen alternatives can generate. Figure 11 illus-trates the amount of job created per renewable energy worldwide. In this figure, we observe that solar creates more jobs per GWh than any other

RES. These data are valid for the developed countries. The situation in Ghana is likely to be different.

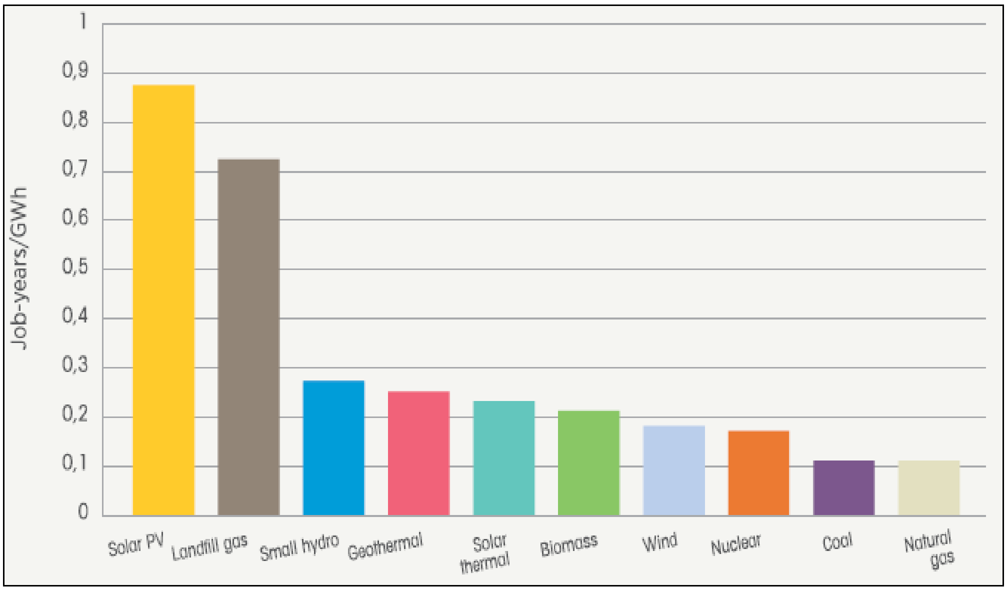


Figure 10: Comparison of job creation-year across different Energy technologies (Job-Year/GWh) hk,u (Wei et al. 2010 as illustrated in IRENA 2011b)

Infrastructure

- Transport: Transport Infrastructure is one of the key criteria for biomass energy but also for wind energy. Good infrastructure reduces logistic cost and facilitates the supply chain.

The proposed AHP model for the selection of renewable energy for Ghana is presented in Figure 11

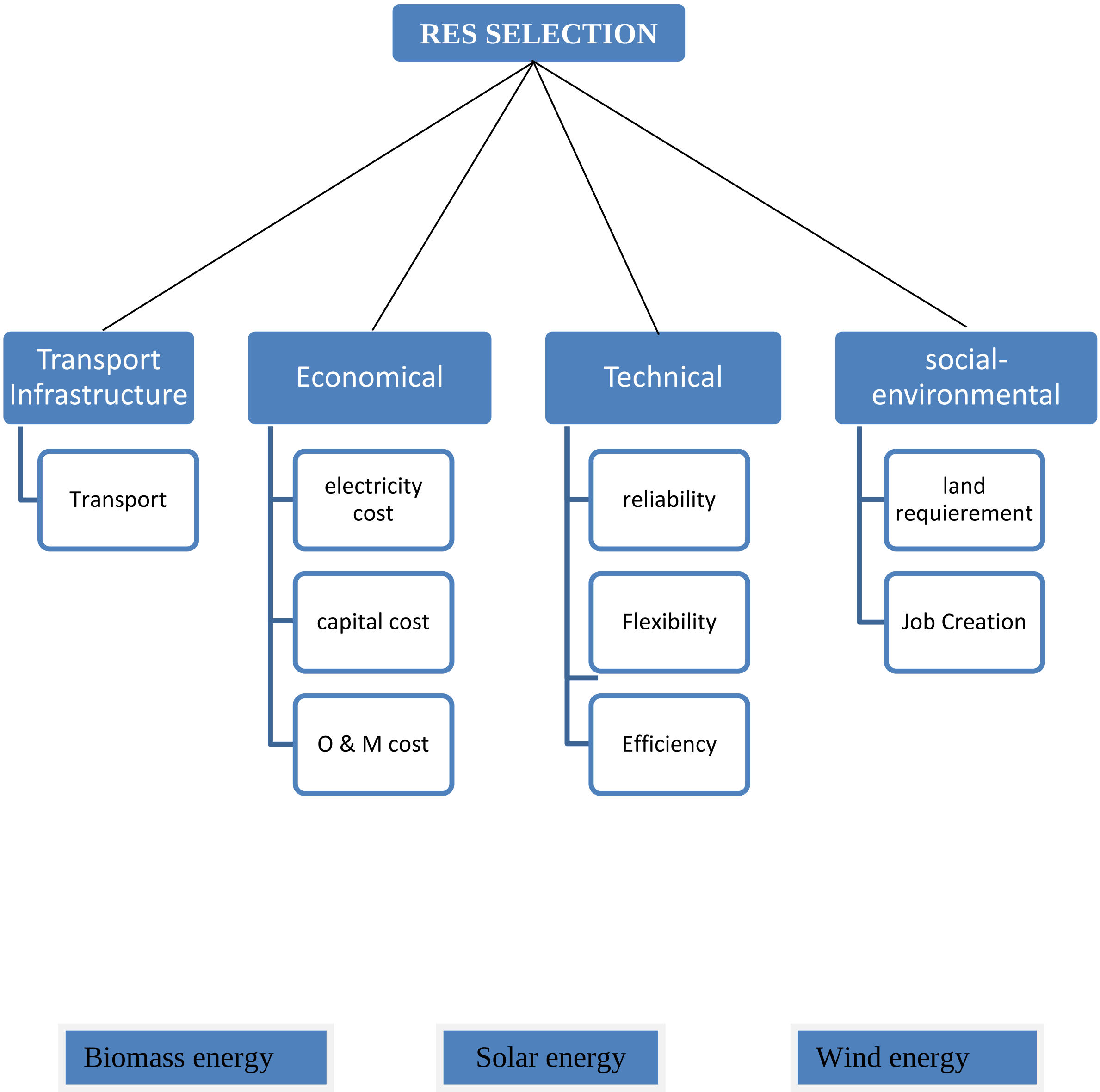


Figure 11: Proposed AHP model for Ghana

5 METHOLOGY

In this chapter, the methodology adopted in the research is presented.

5.1 Data Gathering Method

The paper firstly used the available literature review in order to determine the criteria and sub-criteria used in previous studies. Then the corresponding criteria and sub-criteria impacting the RES in Ghana are determined by comparing the economic situation of countries analyzed in previous studies. The countries of similar economic dilemma are likely to face the same problem, therefore, they need almost the same types of solution. It has to be reminded that some factors that have impact on the selection of RES are missing; a new list of sub-criteria is proposed that could be considered in the selection of RES for a developing country.

This study utilized a questionnaire survey to gather primary data for analysis. The questionnaire was distributed to a group of energy experts. The questionnaire is related to the criteria and sub-criteria determined in the literature review. The questionnaire consist of tables in which, the expert are invited to rank according to goal which criteria is better than the other, followed by the ranking of sub-criteria against others sub-criteria. The data obtained from this comparison were put in a table and used to determine the RES for Ghana. The questionnaire used and the experts' responses is presented in Appendix A.

5.2 Data Analysis Method

As stated in the literature review, the AHP method is used in this study. The AHP software is available online and was used in the determination of the result (Make It Rational, 2013) . The Eigen values, the normalized principal Eigen vectors were calculated using the Android Matrix Operation Calculator application. The calculations are presented in Appendix B.

6 RESULTS AND FINDINGS

The following section present the result and the findings obtained from the AHP methodology used.

6.1 Results

After computing the result of the survey in the AHP software, it has been found that the criteria and sub-criteria used were not all having the same importance. Some criteria appear to be critical for RES selection while others were of little importance. The same observation was also valid concerning the sub-criteria used in the study. The criteria and sub-criteria with their global and local weight are presented in Table 19. As shown in the table, the economic criterion emerged as the most important criterion with a global weight of 38.14 %, followed by transport with a weight of 28.46%. Technical and socio-environmental criteria obtained respectively 21.05% and 12.35%. This implies that economic and transport criteria are the criteria that have to be first considered when selecting RES for off-grid project.

Table 19. Criteria and sub-criteria weights

Criteria and sub-criteria	Global weight [%]	Local weight [%]
Economic	**38.14**	**38.14**
-Capital cost	19.14	50.17
-O & M cost	9.49	24.89
-Electricity cost	9.42	24.94
Technical	**21.05**	**21.05**
-Reliability	13.7	65.09
-Efficiency	4.8	22.79
-Flexibility	2.55	12.12
Socio-environmental	**12.35**	**12.35**
-Land requirement	5.76	46.64
-Job creation	6.59	53.36
Infrastructure(Transport)	**28.46**	**28.46**

As observed in Table 19, economic criterion is the most important criterion with a global weight of 38.14%. That means that priority will be given to alternatives that are affordable. From the analysis, alternatives having low economic aspects when comparing will have higher percentage ranking. Biomass presents the lowest economic aspect with a weight of 48.18% against 37.44% for solar and 14.38 % for wind as illustrated in Figure 12. Based on the economic criterion, biomass will be therefore selected.

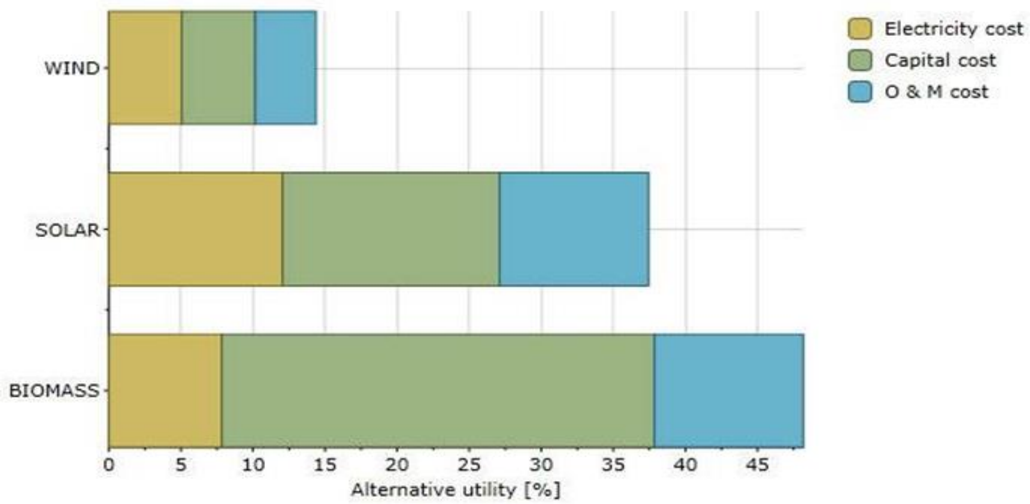


Figure 12**.** Ranking in context of economic criteria

Infrastructure transport is the second most important criterion with a global weight of 28.46%. Alternatives that do not require much transportation or are closed to the transportation network are considered better. The result of the study shows that solar does not require as much transportation as wind and biomass. Solar obtained a weight of 53.67 % as shown in Figure 13.

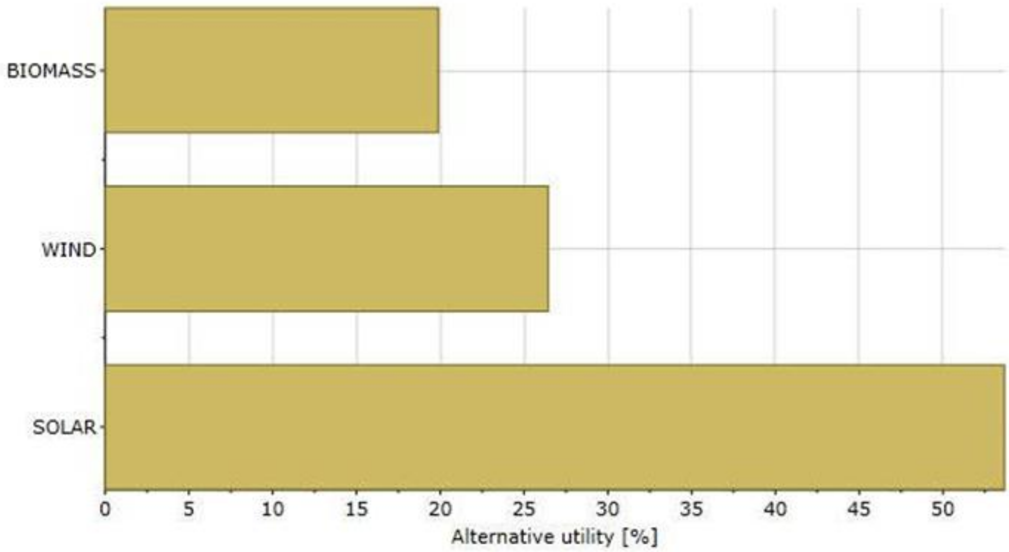


Figure 13. Ranking in context of transport infrastructure

With a global weight of 21.05%, technical criteria emerged as the third most important criteria that have to be considered when selecting RES. The result of the analysis shows that biomass is the best solution as far as technical aspect is considered. Biomass obtained 57.52% as shown in Figure 14.

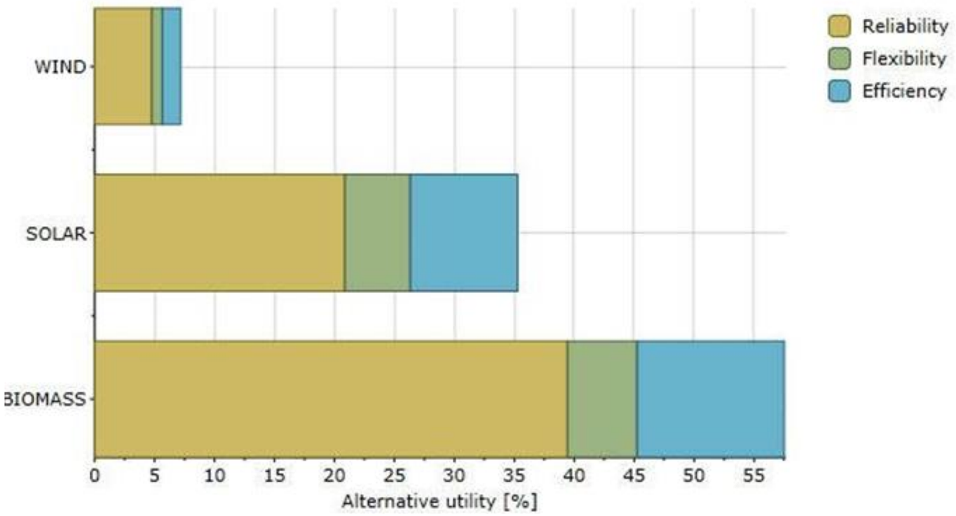


Figure 14. Ranking in context Technical criterion

With a global weight of 12.35%, socio-environmental criterion obtained the lowest ranking weight. Nevertheless, the result shows solar alternatives will be of huge benefit for the socio-environmental development of the rural area, as illustrated in Figure 15.

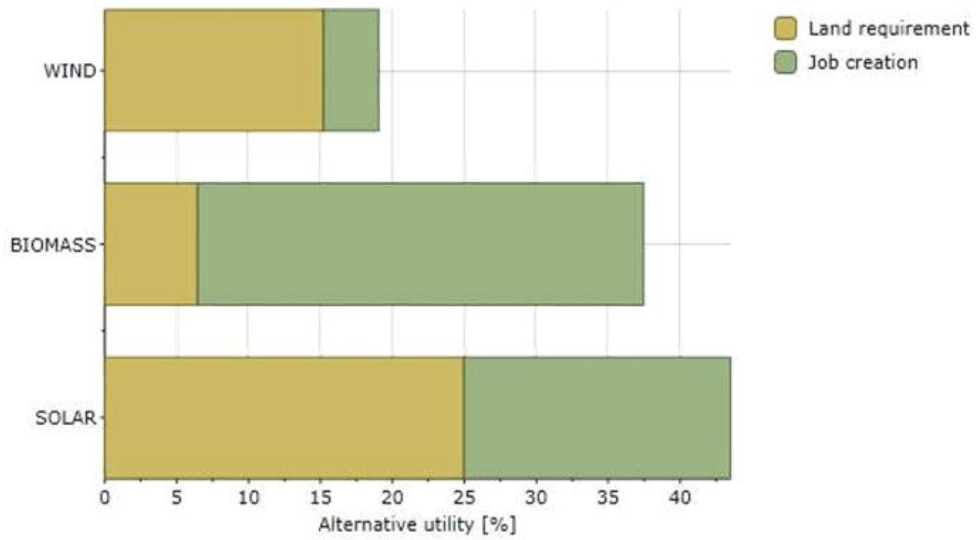


Figure 15: Ranking in context socio-environmental

Capital cost is the most important sub-criteria under the economic criteria. With a global weight of 19.14%, alternatives having low capital cost would be preferred than those having huge capital cost. Biomass emerged as the alternatives having low capital cost with a weight of 59.82 %. Solar and wind alternatives obtained 30.01 % and 10.17 % respectively as show in Figure 16.

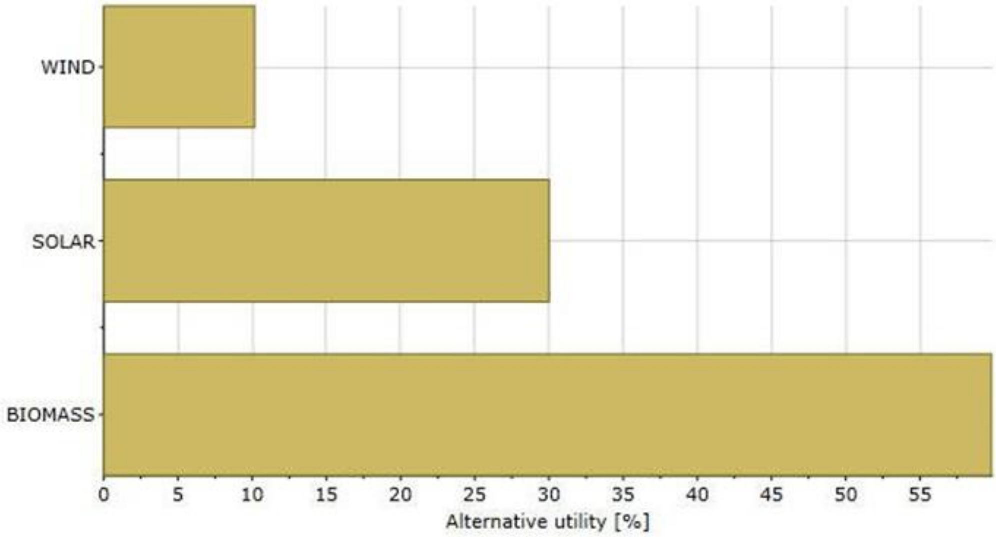


Figure 16. Evaluation in context of capital cost

Reliability is the second very important sub-criteria with a global weight of 13.7%. This implies that the experts think the reliability factor of the RETs is of great importance for Ghanaians and they attached a huge importance to the functionality of the chosen technology. The result of the analysis shows that biomass and solar are the most reliable sources with a weight of 47.9% and 44.88 %. Wind obtained 7.22%. See figure 17.

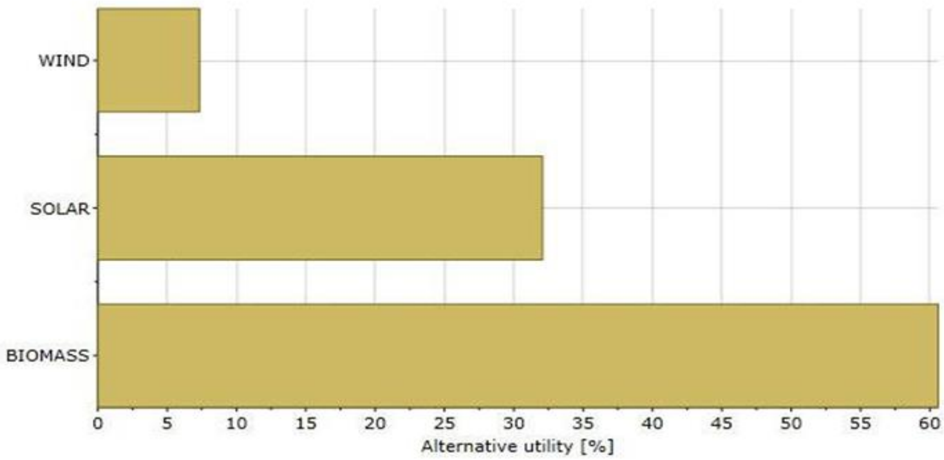


Figure 17. Evaluation in context of reliability

Job creation emerged the as the most important sub-criteria under socio-environmental criterion with a relative local weight of 53.36% against 46.64 % for land requirement. This means a lot is also expected from the renewable energy sources chosen in terms of creation of job. As presented in figure 18, biomass is likely to offer more job opportunities than any other alternatives.

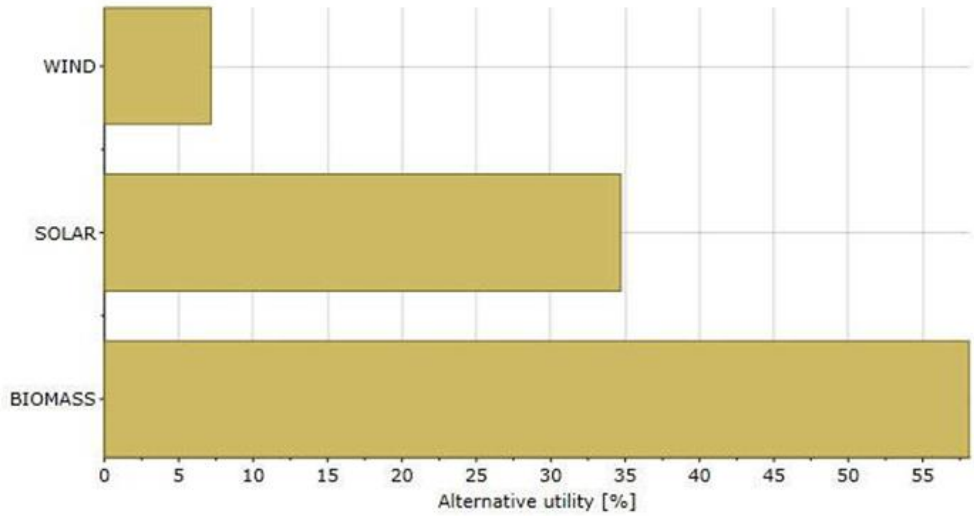


Figure 18**.** Evaluation in context of job creation

These were the description of the most relevant criteria and sub-criteria of the result. The total result of the AHP software study is presented in Appendix C. The following section presents the finding of the study.

6.2 Findings

The overall results of the study has been tabulated and presented in Figure 19. Figure 19 shows the weaknesses and the strengths of each alternative. It observed that biomass outranks the others technologies in economic, technical aspects but lack behind when transport and socio-environmental aspects are considered. Solar lacks behind in economical and socio-environmental aspect, but outranks in transport and infrastructure. Wind energy performs poorly in all the given criteria.

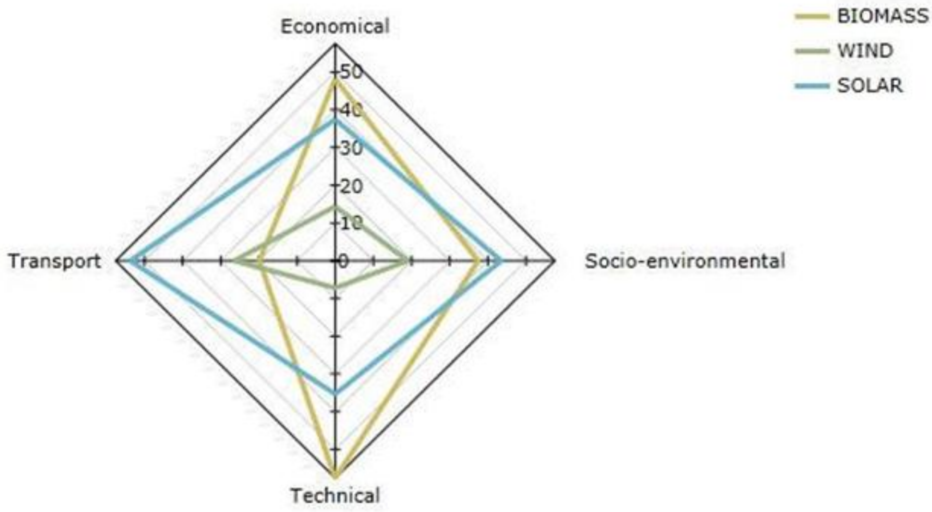


Figure 19: Criteria vs Alternatives

According to the AHP tool developed in this study, solar energy emerged as the solution for providing electricity to rural areas of Ghana; followed by biomass energy. Wind energy emerged as the non-suitable RES for rural areas in Ghana. The priority weight of solar power is 42.35% closely followed by biomass, 40.77% and lastly 16.88% for wind. The results are presented in Table 20.

Table 20.Final result

Alternatives	Total	Technical	Economical	Transport	Socio-environmental
BIOMASS	**40.77**	12.1	18.38	5.66	4.63
WIND	**16.88**	1.51	5.48	7.53	2.35
SOLAR	**42.35**	7.43	14.28	15.27	5.37

7 CONCLUSIONS

Despites numerous efforts to improve energy access in Ghana, with an electrification rate of 52%, rural areas do not have access to electricity. This study proposed a solution to this situation by determining which RES will be suitable for an off-grid connection in rural areas in Ghana. The AHP was the MCDA methods used. In this study, an overview and availability of RES was presented. It has been found that Ghana possesses enough RES in order to provide electricity to its rural population. The available RES in Ghana are: solar energy, biomass energy and wind energy. In order to select the suitable RES for rural electrification, criteria and sub-criteria were determined. An effective approach of the rural electrification dilemma would consider a total of six criteria. However, due to some limitations, four criteria were selected. Therefore, the AHP method model consisted of four criteria, eight sub-criteria and three alternatives. A questionnaire was used as data gathering methodology. The experts, all from Ghana and having renewable energy qualification, made their responses valuable. The experts were asked to compare criteria and sub-criteria. After their ranking, the values obtained were computed in the AHP software. The AHP model result showed that solar energy could have an immensely impact on the electrification of rural areas in Ghana. The study showed that experts considered that solar power could solve the situation with 42.35 % chance better than other RES, solar power is closely followed by biomass with 40.77%.

Though the result shows a slight difference between solar and biomass, one can, however, state that transportation infrastructure is of critical importance if Ghana or any African country that would like to ensure electricity access to its rural population. The result is shown in Figure 20, where biomass largely outranks solar power in the technical and economic aspect but is largely surpassed by solar energy in transport criteria.

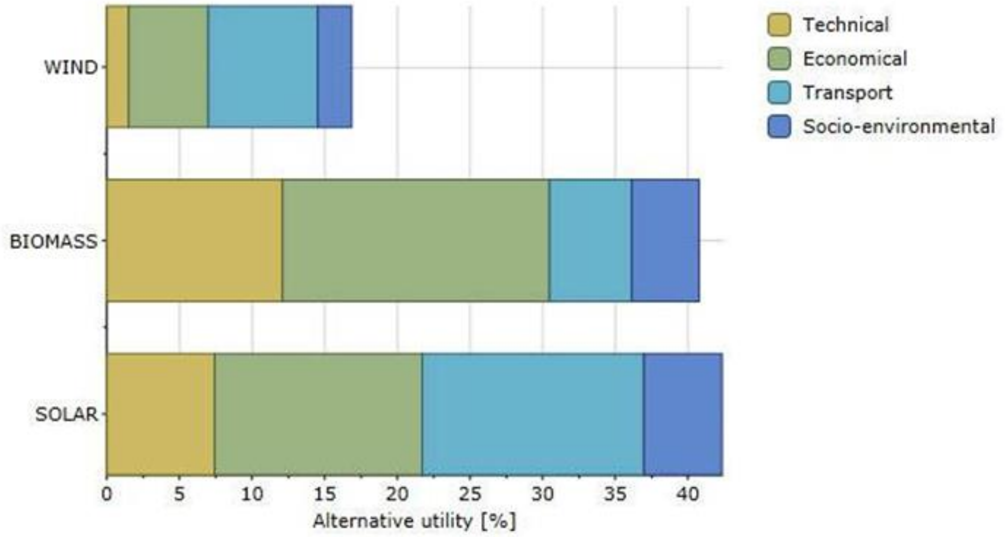


Figure 20: RES ranking

8 RECOMMENDATIONS

This study tends to establish facts how to improve the electricity production for cities and the generation of electricity for rural areas where there is not electricity access.

1. The analysis and the selection of RETs with the aid of the AHP methodology could have been much accurate if one can divide the solar energy technology into one that really meets the energy need in Ghana; the AHP method could also have been used to determine which solar energy technology production would work in Ghana. Further studies can be directed to the selection of renewable energies technologies in order to determine which technologies once use will contribute and specially adapt to the conditions of the countries.
2. A further study with the AHP tool can be carried out to find out which of the biomass feedstock can be utilize for effective electricity production in Ghana.
3. The selection of RES for an on-grid project can be done using the criteria and sub-criteria elaborated in this study.
4. The sub-criteria used in this study can be subject to further improvement
5. This study has raised the need to also investigate the factors investors could consider when desiring to invest in RE in developing countries.
6. For further study, the author proposes that generator set should be used alongside with RES in order to effectively determine mean for electricity production in rural areas in Ghana.
7. It is also proposed that a further study could consider all the criteria and sub-criteria illustrated in this study.

REFERENCES

Brown, P. & Whitney, G., 2011. U.S. Renewable Electricity Generation: Resources and Challenges , s.l.: Congressional Research Service.

A, B. et al., 2011. Renewable energies in Africa, Luxembourg: JRC Scientific and Technical Reports.

Arash , S., Taimaz, . L. & Ali , M., 2012. Procedia - Social and Behavioral Sciences. Evaluation of renewable energy sources for generating electricity in province of Yazd: a fuzzy MCDM approach, Volume 62, p. 1095 – 1099.

Bosiako, P. A., 2011. GhanaWeb.
http://www.ghanaweb.com/GhanaHomePage/education/artikel.php?ID=208962
Accessed februry 2014

Cengiz , K. & Ihsan, . K., 2010. Expert Systems with Applications. A fuzzy multicriteria methodology for selection among energy alternatives, Volume 37, p. 6270–6281.

Communications Unit, MoEP, 2013. Elecnor Foundation Installs 1286 solar systems in 330 communities.
http://www.energymin.gov.gh/?p=1509
Accessed March 2014

Demirtas, O., 2013. International Journal of Energy Economics and Policy. Evaluating the Best Renewable Energy Technology for Sustainable Energy Planning, Volume 3, pp. 23-33.

GLOBAL Wind EnErGy Council, 2012. Global Wind Energy Outlook.
: http://www.gwec.net/wp-content/uploads/2012/11/GWEO_2012_lowRes.pdf
Accessed April 2014

International Energy Agency, 2013. World Energy Outlook.
http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/
Accessed januay 2014

IRENA, 2012. Summary for Policy makers: Renewable Power Generation Costs.
http://www.irena.org/DocumentDownloads/Publications/Renewable_Power_Generation_Costs.pdf
Accessed May 2014

Kampb, K. F. A., Sune, T. T., Edem, C. B. & Hanne, Ø., 2014. Resources, Conservation and Recycling. Assessment of biomass residue availability and bioenergyyields in Ghana, Volume 86, p. 28–37.

Make It Rational, 2013. Make It Rational.
Available at: http://makeitrational.com/analytic-hierarchy-process/ahp-software#!prettyPhoto
Accessed 31 May 2014

Mohammeda, Y. S., A., S. M., N., B. & R., S., 2013. Renewable and Sustainable Energy Reviews. An overview of agricultural biomass for decentralized rural energy in Ghana, Volume 20, p. 15–25.

Moses , H. D., Sai , G. & Essel, . B. . H., 2011. Renewable and Sustainable Energy Reviews. A comprehensive review of biomass resources and biofuels potential in Ghana, 15(1), p. 404–415.

Muhammad , A. & Tugrul , D. U., 2011. Energy for Sustainable Development. Selection of renewable energy technologies for a developing county: A case, Volume 15, p. 420–435.

Obeng, G. Y., Kemausuor, F., Brew-Hammond, A. . & Duker , A., 2009. ecreee. [http://www.ecreee.org/sites/default/files/event-att/ghana_energy_access_review.pdf
Accessed March 2014

OpenEI, n.d. Ghana Wind Energy Resource Mapping Activity.
http://en.openei.org/datasets/files/717/pub/ghanawindreport_245.pdf
Accessed May 2014

Otu-Danquah, K. A., 2012. STATUS OF BIOMASS RESOURCE ASSESSMENT IN GHANA.
http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2012_events/WGCB_Activity_1_Rome_13-14_November_2012/2.5_-_GHANA.pdf
Accessed May 2014

Salman , A. & Razman , T. M., 2013. Renewable Energy. Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia, Volume 63, p. 458e466.

Schillings, C., Meyer, R. & Trieb, F., 2004. High Resolution Solar Radiation Assessment for Ghana, Stuttgart: DLR - Deutsches Zentrum für Luft- und Raumfahrt, e.V..

Schill, S. R., 2013. Biomass Magazine.
http://biomassmagazine.com/articles/9444/iea-task40-biomass-provides-10-percent-of-global-energy-use
Accessed April 2014

Simona , O. . N., Floortje , A. & Marko , . P. H., 2012. Renewable and Sustainable Energy Reviews. Why does renewable energy diffuse so slowly? A review of innovation system problems, Volume 16(6), p. 3836–3846.

Tolga , K. & Cengiz , K., 2010. Energy. Multicriteria renewable energy planning using an integrated fuzzy: The case of Istanbul, Volume 35, pp. 2517-2527.

Volta River Authority, 2013. VRA Inaugurates first Solar Power Plant.
http://www.vraghana.com/media/2013/may/news_04.php
Accessed February 2014

VOLTA RIVER AUTHORITY, 2014. Ghana's Power Outlook-Facts & figures.
http://www.vraghana.com/media/2014/march/news_02.php
Accessed 16 April 2014

World Bank, 2013. LIST OF DEVELOPING COUNTRIES.
file:///C:/Users/e1300001/Downloads/listofDevelopingcountries2013.pdf.pdf
Accessed April 2014

World Bank, 2014. http://data.worldbank.org/country/ghana.
http://www.worldbank.org/
Accessed 23 April 2014

APPENDIX A

TITLE:	NAMES:	OCCUPATION:
EXPERT 1	RENEWABLE ENERGY EXPERT (Ph.D.)	Dr of Sc. In Business Admni.
EXPERT 2	ENERGY EXPERT (M.sc.)	RESEARCHER/DOCTORAL STUDENT
EXPERT 3	RENEWABLE ENERGY EXPERT (B.sc)	Bsc. ENERGY STUDENT VAMK
EXPERT 4	ENERGY EXPERT ECREEE (M.sc)	

1) Complete a pair wise comparison with respect to the RES for Ghana					
	Expert 1	Expert 2	Expert 3	Expert 4	
ECONOMICAL					SOCIO-ENVIRONMENTAL
TECHNICAL					ECONOMICAL
SOCIO-ENVIRONMENTAL					TECHNICAL
T. INFRASTRUCTURE					TECHNICAL
T. INFRASTRUCTURE					ECONOMICAL
T. INFRASTRUCTURE					SOCIO-ENVIRONMENTAL
2) Complete a pairwise comparison taking into account the ECONOMICAL criteria					
	Expert 1	Expert 2	Expert 3	Expert 4	
CAPITAL COST					O & M COST
ELECTRICITY COST					O & M COST
ELECTRICITY COST					CAPITAL COST
3) Complete a pair wise comparison taking into account the TECHNICAL criteria					
	Expert 1	Expert 2	Expert 3	Expert 4	
RELIABILITY					FLEXIBILITY
EFFICIENCY					RELIABILITY
EFFICIENCY					FLEXIBILITY
4)Complete a pair wise comparison taking into account SOCIO-ENVIRONMENTAL aspect					
	Expert 1	Expert 2	Expert 3	Expert 4	
JOB CREATION					LAND REQUIREMENT

5) Complete a pair wise comparison taking into account alternatives with less ELECTRICITY COST					
	Expert 1	Expert 2	Expert 3	Expert 4	
BIOMASS ENERGY					WIND ENERGY
SOLAR ENERGY					WIND ENERGY
SOLAR ENERGY					BIOMASS ENERGY
7) Complete a pair wise comparison taking into account alternatives with less CAPITAL COST					
	Expert 1	Expert 2	Expert 3	Expert 4	
BIOMASS ENERGY					WIND ENERGY
SOLAR ENERGY					WIND ENERGY
SOLAR ENERGY					BIOMASS ENERGY
8) Complete a pair wise comparison taking into account alternatives with less O & M COST					
	Expert 1	Expert 2	Expert 3	Expert 4	
BIOMASS ENERGY					WIND ENERGY
SOLAR ENERGY					WIND ENERGY
SOLAR ENERGY					BIOMASS ENERGY
10) Complete a pair wise comparison taking into account alternatives with high RELIABILITY					
	Expert 1	Expert 2	Expert 3	Expert 4	
BIOMASS ENERGY					WIND ENERGY
SOLAR ENERGY					WIND ENERGY
SOLAR ENERGY					BIOMASS ENERGY

11) Complete a pair wise comparison taking into account alternatives with high FLEXIBILITY					
	Expert 1	Expert 2	Expert 3	Expert 4	
BIOMASS ENERGY					WIND ENERGY
SOLAR ENERGY					WIND ENERGY
SOLAR ENERGY					BIOMASS ENERGY
12) Complete a pair wise comparison taking into account alternatives with more EFFICIENCY					
	Expert 1	Expert 2	Expert 3	Expert 4	
BIOMASS ENERGY					WIND ENERGY
SOLAR ENERGY					WIND ENERGY
SOLAR ENERGY					BIOMASS ENERGY
13) Complete a pair wise comparison taking into account alternatives with less LAND REQUIEREMENTS					
	Expert 1	Expert 2	Expert 3	Expert 4	
BIOMASS ENERGY					WIND ENERGY
SOLAR ENERGY					WIND ENERGY
SOLAR ENERGY					BIOMASS ENERGY

15) Complete a pair wise comparison taking into account alternatives with more JOB CREATION					
	Expert 1	Expert 2	Expert 3	Expert 4	
BIOMASS ENERGY					WIND ENERGY
SOLAR ENERGY					WIND ENERGY
SOLAR ENERGY					BIOMASS ENERGY
16) Complete a pair wise comparison taking into account alternatives close to INFRASTRUCTURE					
	Expert 1	Expert 2	Expert 3	Expert 4	
BIOMASS ENERGY					WIND ENERGY
SOLAR ENERGY					WIND ENERGY
SOLAR ENERGY					BIOMASS ENERGY

APPENDIX B

EXPERT 1

A- **Pair wise comparison of energy resources to the O & M cost.**

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	0.2	0.14	0.07718
SOLAR	5	1	1	0.43332
WIND	1.14	1	1	0.48948

By using the Matrix operation application, the Eigen value is **3.014** and the Eigen vector w is: [0.1171, 0.6594, 0.7426],

Sum=0.1171+0.6574+0.7426=**1.5171**

- The sum is**: 1.5171.** The normalized principal vector is obtained by dividing Eigen vector by the Sum. Hence, the normalized principal vector is:

[0.07718, 0.43332, 0.48948]

Using the ratio CI = (λ_{max} – n) / (n – 1), and where λ_{max}=**3.014** and n=3. We calculate the Consistency index, **CI= 0.007**

n being 3, the random consistency is **0.58**, hence the consistency ratio is obtained by applying: $CR = \frac{CI}{RI} = \mathbf{0.01207}$

- **CR <0.1, the judgment is considered as valid.**

B- Pair wise comparison of energy resources to electricity cost.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	3.03	7	0.68326
SOLAR	0.33	1	2	0.21495
WIND	0.14	0.5	1	0.10179

Eigen value is: **2.9959** and the Eigen vector is: **[0.9444, 0.2971, 0.1407],** the sum is: **1.3822.** Hence, the normalized principal vector is:

[0.68326, 0.21495, 0.10179].

The consistency index is CI is: **CI=0.00205.** Hence the consistency ratio is: **CR=0.00353**

- **CR <0.1, the judgment is considered as valid.**

C- Pair wise comparison of energy resources to capital cost.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	**0.2**	0.2	0.09090
SOLAR	5	1	1	0.45455
WIND	5	1	1	0.45455

Eigen value is: **3.0** and the Eigen vector is: **[0.3464, 1.7321, 1.7321**], the sum is: **3.8106.** Hence, the normalized principal vector (NPV) is:

[0.09090, 0.45455, 0.45455]

The consistency index is CI is: **CI=0** Hence the consistency ratio is:

CR= 0

- **CR <0.1, the judgment is considered as valid.**

D- Pair wise comparison of energy resources to reliability.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	**3.03**	7	0.68326
SOLAR	0.33	1	2	0.21495
WIND	0.14	0.5	1	0.10179

Eigen value is: **2.9959** and the Eigen vector is: [0.9444, 0.2971, 0.1407]. The sum is: **1.3832.** Hence, the normalized principal vector (NPV) is:

[0.68326, 0.21495, 0.10179]

The consistency index is CI is: **CI=0.00205.** Hence the consistency ratio is: **CR=0.00353**

- **CR <0.1, the judgment is considered as valid.**

E- Pair wise comparison of energy resources to flexibility.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	**0.25**	5	0.2373
SOLAR	4	1	8	0.6972
WIND	0.2	0.13	1	0.065

Eigen value is: **3.039** and the Eigen vector is: [**0.321, 0.9429, 0.0884**]. The sum is **1.3523**. Hence, the normalized principal vector (NPV) is:

[0.2373, 0.6972, 0.06537]

The consistency index is CI is: **CI=0.056** Hence the consistency ratio is:

CR=0.09

- **CR <0.1, the judgment is considered as valid.**

F- Pair wise comparison of energy resources to efficiency.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	**1**	8	0.48840
SOLAR	1	1	6	0.44318
WIND	0.13	0.17	1	0.06843

Eigen value is: **3.0285** and the Eigen vector is: [0.7366, 0.6684, 0.1032]. The sum is: **1.5082.** Hence, the normalized principal vector (NPV) is:

[0.048840, 0.44318, 0.06843]

The consistency index is CI is: **CI=0.01425.** Hence the consistency ratio is: **CR=0.02457**

- **CR <0.10, the judgment is considered as valid.**

G- Pair wise comparison of energy resources to land requierement.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	**0.2**	0.14	0,07718
SOLAR	5	1	1	0.43332
WIND	7.14	1	1	0.48948

Eigen value is: **3.014** and the Eigen vector is: [**0.1171, 0.6594, 0.7426**]. The sum is **1,5171**. Hence, the normalized principal vector (NPV) is:

[0.07718, 0.43332, 0.48948]

The consistency index is CI is: **CI=0,007.** Hence the consistency ratio is:

CR=0.01207

- **CR <0.1, the judgment is considered as valid.**

H- Pair wise comparison of energy resources to Job creation

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	**2**	7	0.57454
SOLAR	0.5	1	7	0.36124
WIND	0.14	0.14	1	0.06422

Eigen value is**: 3.0399** and the Eigen vector is: **[0.8428, 0.5299, 0.0942].** The sum is: **1.4669.** Hence, the normalized principal vector (NPV) is:

[0.57454, 0.36124, 0.06422]

The consistency index is CI is: **CI= 0.01995.** Hence the consistency ratio is:

CR= 0.03440

- **CR <0.10, the judgment is considered as valid.**

EXPERT 2

A- **Pair wise comparison of energy resources to the O & M cost.**

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	9	0.47385
SOLAR	1	1	9	0.47385
WIND	0.11	0.11	1	0.05229

By using the Matrix operation application, the Eigen value is **2.9933**and the Eigen vector w is: [0.705, 0.705, 0.0778],

Sum=0.705+0.705+0.0778=**1.4878**

- The sum is**: 1.4878.** The normalized principal vector is obtained by dividing Eigen vector by the Sum. Hence, the normalized principal vector is:

[0.47385, 0.47385, 0.05229]

Using the ratio CI = (λ_{max} – n) / (n – 1), and where λ_{max}=**2.9933**and n=3. We calculate the Consistency index, **CI= 0.00335**

n being 3, the random consistency is **0.58**, hence the consistency ratio is obtained by applying: $CR = \frac{CI}{RI} =$ **0.00578**

- **CR <0.1, the judgment is considered as valid.**

B- Pair wise comparison of energy resources to electricity cost.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	9	0.47385
SOLAR	1	1	9	0.47385
WIND	0.11	0.11	1	0.05229

Eigen value is: **2.9933** and the Eigen vector is: **[0.705, 0.705, 0.07780],** the sum is: **1.4878 Hence**, the normalized principal vector is:

[0.47385, 0.47385, 0.052290]

The consistency index is CI is: **CI=0.00335** Hence the consistency ratio is: **CR=0.00578**

- **CR <0.1, the judgment is considered as valid.**

C- Pair wise comparison of energy resources to capital cost.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	9	0.47385
SOLAR	1	1	9	0.47385
WIND	0.11	0.11	1	0.05229

Eigen value is: **2.9933** and the Eigen vector is: **[0.705, 0.705, 0.07780],** the sum is: **1.4878** Hence, the normalized principal vector is:

[0.47385, 0.47385, 0.052290]

The consistency index is CI is: **CI=0.00335** Hence the consistency ratio is: **CR=0.00578**

- **CR <0.1, the judgment is considered as valid.**

D- Pair wise comparison of energy resources to reliability.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	9	0.47385
SOLAR	1	1	9	0.47385
WIND	0.11	0.11	1	0.05229

Eigen value is: **2.9933** and the Eigen vector is: **[0.705, 0.705, 0.07780],** the sum is: **1.4878** Hence, the normalized principal vector is:

[0.47385, 0.47385, 0.052290]

The consistency index is CI is: **CI=0.00335** Hence the consistency ratio is: **CR=0.00578**

- **CR <0.1, the judgment is considered as valid.**

E- Pair wise comparison of energy resources to flexibility.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	9	0.47385
SOLAR	1	1	9	0.47385
WIND	0.11	0.11	1	0.05229

Eigen value is: **2.9933** and the Eigen vector is: **[0.705, 0.705, 0.07780],** the sum is: **1.4878** Hence, the normalized principal vector is:

[0.47385, 0.47385, 0.052290]

The consistency index is CI is: **CI=0.00335** Hence the consistency ratio is: **CR=0.00578**

- **CR <0.1, the judgment is considered as valid.**

F- Pair wise comparison of energy resources to efficiency.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	9	0.47385
SOLAR	1	1	9	0.47385
WIND	0.11	0.11	1	0.05229

Eigen value is: **2.9933** and the Eigen vector is: **[0.705, 0.705, 0.07780],** the sum is: **1.4878** Hence, the normalized principal vector is:

[0.47385, 0.47385, 0.052290]

The consistency index is CI is: **CI=0.00335** Hence the consistency ratio is: **CR=0.00578**

- **CR <0.1, the judgment is considered as valid.**

G- Pair wise comparison of energy resources to land requirement.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	9	0.47385
SOLAR	1	1	9	0.47385
WIND	0.11	0.11	1	0.05229

Eigen value is: **2.9933** and the Eigen vector is: **[0.705, 0.705, 0.07780],** the sum is: **1.4878** Hence, the normalized principal vector is:

[0.47385, 0.47385, 0.052290]

The consistency index is CI is: **CI=0.00335** Hence the consistency ratio is: **CR=0.00578**

- **CR <0.1, the judgment is considered as valid.**

H- Pair wise comparison of energy resources to Job creation.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	9	0.47385
SOLAR	1	1	9	0.47385
WIND	0.11	0.11	1	0.05229

Eigen value is: **2.9933** and the Eigen vector is: **[0.705, 0.705, 0.07780],** the sum is: **1.4878** Hence, the normalized principal vector is:

[0.47385, 0.47385, 0.052290]

The consistency index is CI is: **CI=0.00335** Hence the consistency ratio is: **CR=0.00578**

- **CR <0.1, the judgment is considered as valid.**

EXPERT 3

A- **Pair wise comparison of energy resources to the O & M cost.**

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	4	0.44444
SOLAR	1	1	4	0.44444
WIND	0.25	0.25	1	0,11111

By using the Matrix operation application, the Eigen value is **3.0**and the Eigen vector w is: [0.7276, 0.7276, 0.1819],

Sum=0.7276+0.7276+0.1819=**1.6371**

- The sum is**: 1.6371.** The normalized principal vector is obtained by dividing Eigen vector by the Sum. Hence, the normalized principal vector is:

[0.44444, 0.44444, 0.11111]

Using the ratio CI = (λ_{max} – n) / (n – 1), and where λ_{max}=**3.0**and n=3. We calculate the Consistency index, **CI= 0**

n being 3, the random consistency is **0.58**, hence the consistency ratio is obtained by applying: $CR = \frac{CI}{RI} = \mathbf{0}$

CR <0.1, the judgment is considered as valid

B- Pair wise comparison of energy resources to capital cost.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	4	0.44444
SOLAR	1	1	4	0.44444
WIND	0.25	0.25	1	0.11111

Eigen value is: **3.0** and the Eigen vector is: **[0.7276, 0.7276, 0.1819],** the sum is: **1.6371** Hence, the normalized principal vector is:

[0.44444, 0.44444, 0.111110]

The consistency index is CI is: **CI=0.** Hence the consistency ratio is: **CR=0**

- **CR <0.1, the judgment is considered as valid.**

C- Pair wise comparison of energy resources to flexibility.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	4	0.44444
SOLAR	1	1	4	0.44444
WIND	0.25	0.25	1	0.11111

Eigen value is: **3.0** and the Eigen vector is: **[0.7276, 0.7276, 0.1819],** the sum is: **1.6371** Hence, the normalized principal vector is:

[0.44444, 0.44444, 0.111110]

The consistency index is CI is: **CI=0.** Hence the consistency ratio is: **CR=0**

- **CR <0.1, the judgment is considered as valid.**

D- Pair wise comparison of energy resources to reliability.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	9	0.48121
SOLAR	1	1	8	0.46259
WIND	0.11	0.13	1	0.05620

Eigen value is: **3.0122** and the Eigen vector is: **[0.7184, 0.6906, 0.0839],** the sum is: **1.4929** Hence, the normalized principal vector is:

[0.48121, 0.46259, 0.05620]

The consistency index is CI is: **CI=0.0061.** Hence the consistency ratio is: **CR=0.01052**

- **CR <0.1, the judgment is considered as valid.**

E- Pair wise comparison of energy resources to electricity cost.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	0.25	1	0.18402
SOLAR	4	1	2	0.5841
WIND	1	0.5	1	0.2318

Eigen value is: **3.0536** and the Eigen vector is: **[0.281, 0.892, 0.354],** the sum is: **1.527.** Hence, the normalized principal vector is:

[0.184, 0.5841, 0.2318,]

The consistency index is CI is: **CI=0.0268.** Hence the consistency ratio is: **CR=0.046**

- **CR <0.1, the judgment is considered as valid.**

F- Pair wise comparison of energy resources to efficiency.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	1	6	0.46106
SOLAR	1	1	6	0.46106
WIND	0.17	0.17	1	0.07788

Eigen value is: **3.0133** and the Eigen vector is: **[0.7021, 0,7021, 0.1186],** the sum is: **1.5228.** Hence, the normalized principal vector is:

[0.46106, 0.46106, 0.07788]

The consistency index is CI is: **CI=0.00665.** Hence the consistency ratio is: **CR=0.01147**

CR <0.1, the judgment is considered as valid.

G- Pair wise comparison of energy resources to land requirement.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	0,11111	0,14286	0.057
SOLAR	6	1	0,5	0.38
WIND	7	2	1	0.55

Eigen value is: **3.0883** and the Eigen vector is: **[0.0848, 0.5623, 0.8266],** the sum is: **1.4697.** Hence, the normalized principal vector is:

[0.057, 0.38, 0.55]

The consistency index is CI is: **CI=0.04415.** Hence the consistency ratio is: **CR=0.07612069**

CR <0.1, the judgment is considered as valid.

H- Pair wise comparison of energy resources to Job creation.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	3	5	0.29708
SOLAR	2	1	4	0.53997
WIND	0.5	0.33	1	0.44953

Eigen value is: **3.0055** and the Eigen vector is: **[0.466, 0.847, 0.2556],** the sum is: **1.5686.** Hence, the normalized principal vector is:

[0.29708, 0.53997,0.44953,]

The consistency index is CI is: **CI=0.00275.** Hence the consistency ratio is: **CR=0.00474**

CR<0.1, the judgment is considered as valid.

EXPERT 4

A- **Pair wise comparison of energy resources to the flexibility.**

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	2	7	0.566
SOLAR	0,5	1	8	0.37
WIND	0,142857143	0,125	1	0.06

By using the Matrix operation application, the Eigen value is **3.0676** and the Eigen vector w is: [0.8322, 0.5473, 0.0894],

Sum=0.914+0.3916+0.1005= **1,4689**

- The sum is**: 1,4689.** The normalized principal vector is obtained by dividing Eigen vector by the Sum. Hence, the normalized principal vector is:

[0.566, 0.37, 0.06]

Using the ratio CI = (λ_{max} – n) / (n – 1), and where λ_{max}=**3.0**and n=3. We calculate the Consistency index, **CI= 0,0338**

n being 3, the random consistency is **0.58**, hence the consistency ratio is obtained by applying: $CR = \frac{CI}{RI} = 0,05$

CR <0.1, the judgment is considered as valid

B- Pair wise comparison of energy resources to efficiency.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	4	8	0.7071
SOLAR	0,25	1	4	0.222
WIND	0,125	0,25	1	0.070

Eigen value is: **3.0536** and the Eigen vector is: **[0.9496, 0.2991, 0.0942],** the sum is: **1.3429.** Hence, the normalized principal vector is:

[0.7071, 0.222, 0.070,]

The consistency index is CI is: **CI= 0,0268.** Hence the consistency ratio is: **CR= 0,046206897**

CR<0.1, the judgment is considered as valid.

C- Pair wise comparison of energy resources to land requirement.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	0.16667	0.14286	0.068
SOLAR	6	1	2	0.56
WIND	7	0.5	1	0.37

Eigen value is: **3.0574** and the Eigen vector is: **[0.1019, 0.8301, 0.5483],** the sum is: **1.4803.** Hence, the normalized principal vector is:

[0.068, 0.56, 0.37]

The consistency index is CI is: **CI= 0,0287.** Hence the consistency ratio is: **CR= 0,049482759**

CR<0.1, the judgment is considered as valid.

D- Pair wise comparison of energy resources to job creation.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	5	6	0.719085
SOLAR	0,2	1	3	0.1944
WIND	0,166666667	0,33333	1	0.8646

Eigen value is: **3.00733** and the Eigen vector is: **[0.958, 0.2593, 0.1153],** the sum is: **1,3335.** Hence, the normalized principal vector is:

[0.72, 0.194, 0,086,]

The consistency index is CI is: **CI= 0,03665.** Hence the consistency ratio is: **CR= 0,063189655**

CR<0.1, the judgment is considered as valid.

D- Pair wise comparison of energy resources to electricity cost.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	4	4	0.799
SOLAR	0,25	1	1	0.10
WIND	0,25	1	1	0.10

Eigen value is: **0** and the Eigen vector is: **[0.9847, 0.1231, 0.1231],** the sum is: **1,3335.** Hence, the normalized principal vector is:

[0.80, 0.10, 0.10,]

The consistency index is CI is: **CI= 0.** Hence the consistency ratio is: **CR= 0**

CR<0.1, the judgment is considered as valid.

D- Pair wise comparison of energy resources to capital cost.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	5	5	0.833
SOLAR	0,2	1	1	0.083
WIND	0,2	1	1	0.083

Eigen value is: **0** and the Eigen vector is: **[0.9901, 0.099, 0.099],** the sum is: **1,1881**Hence, the normalized principal vector is:

[0.83, 0.083, 0.083,]

The consistency index is CI is: **CI= 0.** Hence the consistency ratio is: **CR= 0**

CR<0.1, the judgment is considered as valid.

D- Pair wise comparison of energy resources to O & M cost.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	5	5	0.833
SOLAR	0,2	1	1	0.083
WIND	0,2	1	1	0.083

Eigen value is: **0** and the Eigen vector is: **[0.9901, 0.099, 0.099],** the sum is: **1,1881**Hence, the normalized principal vector is:

[0.83, 0.083, 0.083,]

The consistency index is CI is: **CI= 0.** Hence the consistency ratio is: **CR= 0**

CR<0.1, the judgment is considered as valid.

D- Pair wise comparison of energy resources to reliability.

	BIOMASS	SOLAR	WIND	NPV
BIOMASS	1	5	7	0.7315
SOLAR	0,2	1	3	0.1883
WIND	0,142857143	0,33333	1	0.080

Eigen value is: **3.0537** and the Eigen vector is: **[0.963, 0.2479, 0.1055],** the sum is: **1.3164** Hence, the normalized principal vector is:

[0.73, 0.1883, 0.080,]

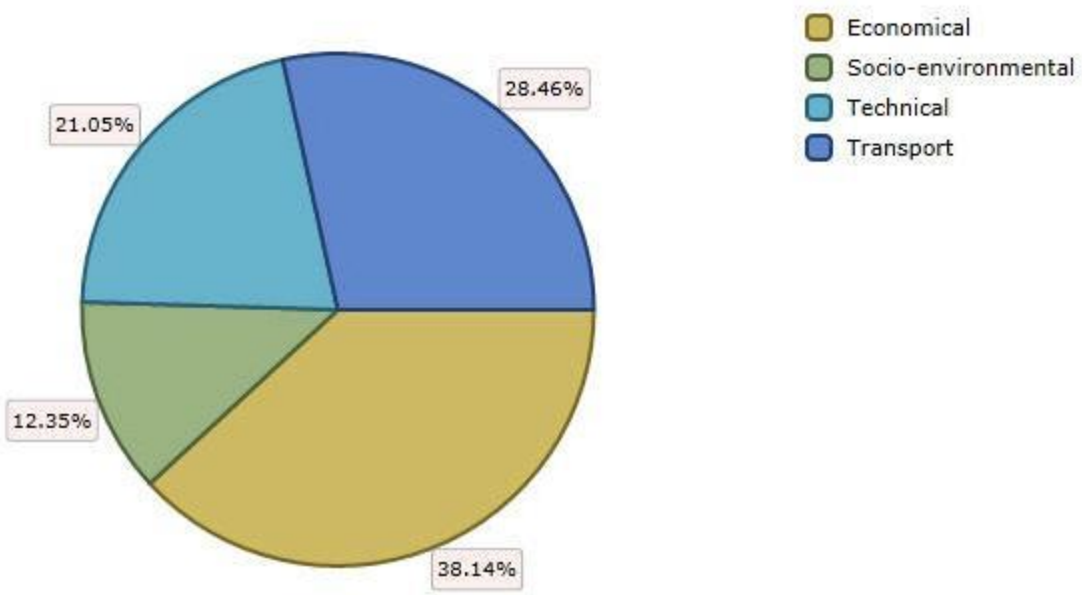
The consistency index is CI is: **CI= 0,02685.**Hence the consistency ratio is: **CR= 0,046293103**

CR<0.1, the judgment is considered as valid.

APPENDIX C

Evaluation in context of: SELECT THE BEST SUITABLE ENRGY SOURCES

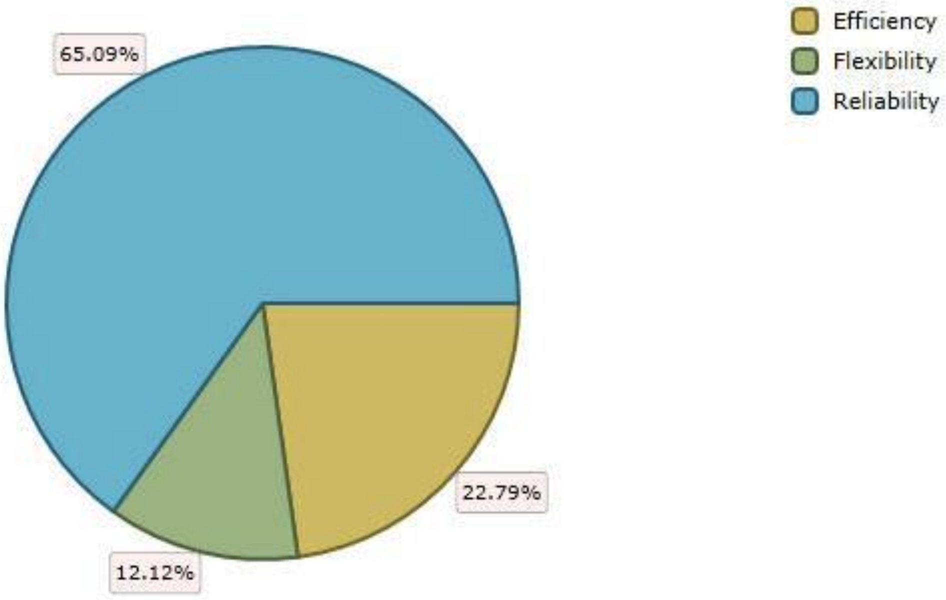
Transport vs. Technical	1.06 : 1
Transport vs. Socio-environmental	2.8 : 1
Economical vs. Transport	1.19 : 1
Technical vs. Socio-environmental	1.07 : 1
Economical vs. Technical	1.5 : 1
Economical vs. Socio-environmental	4.36 : 1



Criterion	Weight
Technical	21.05
Economical	38.14
Transport	28.46
Socio-environmental	12.35

Evaluation in context of: Technical

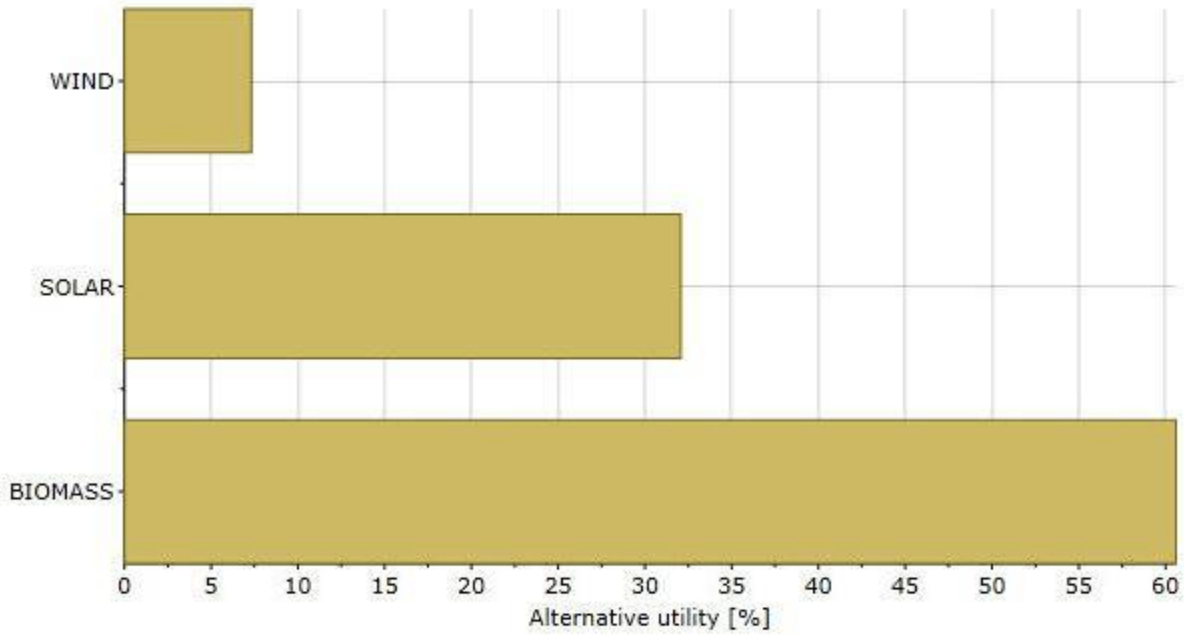
Efficiency vs. Flexibility	1.86 : 1
Reliability vs. Flexibility	5.42 : 1
Reliability vs. Efficiency	2.83 : 1



Criterion	Weight
Reliability	65.09
Flexibility	12.12
Efficiency	22.79

Evaluation in context of: Reliability

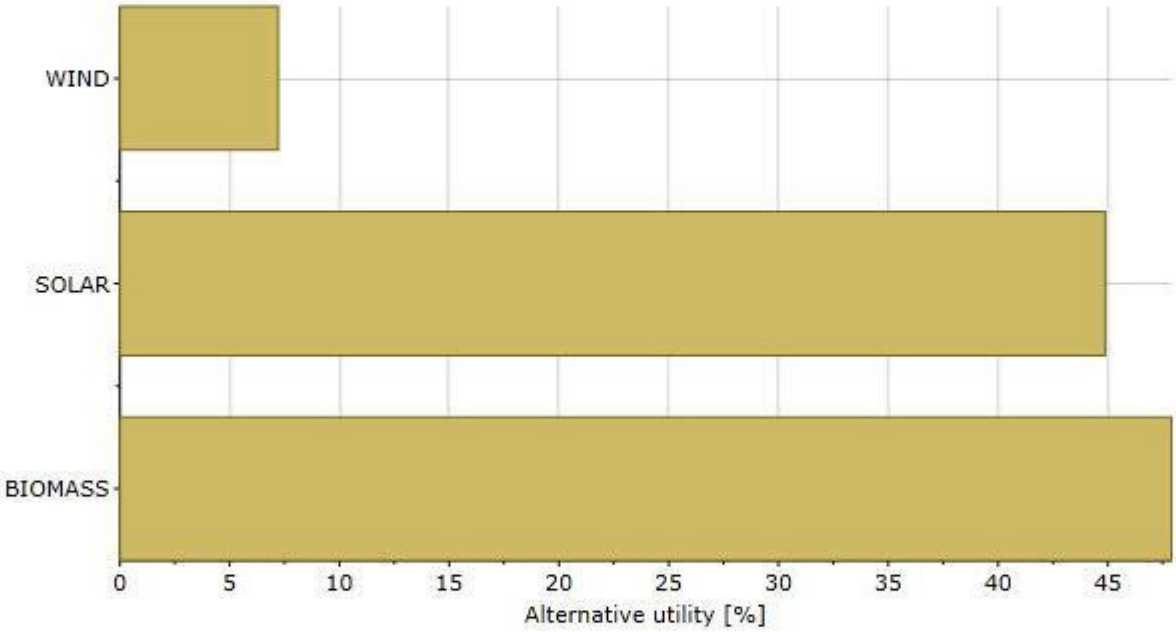
BIOMASS vs. SOLAR	1.97 : 1
SOLAR vs. WIND	4.56 : 1
BIOMASS vs. WIND	7.94 : 1



Alternative	Reliability
BIOMASS	60.6
WIND	7.33
SOLAR	32.07

Evaluation in context of: Flexibility

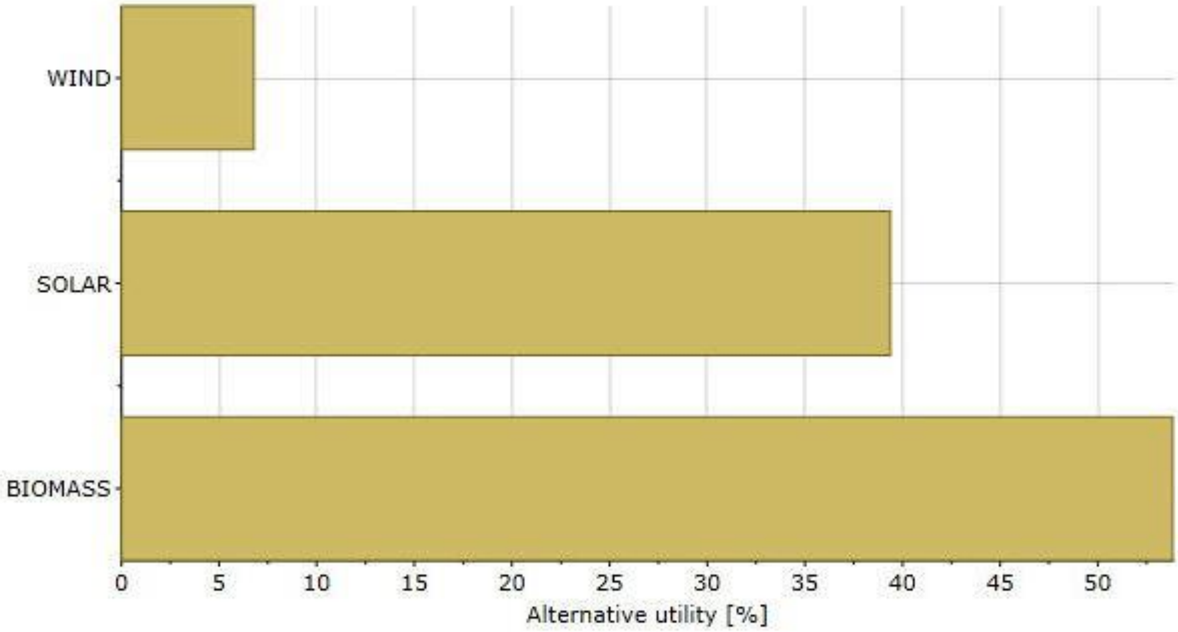
BIOMASS vs. SOLAR	1.19 : 1
SOLAR vs. WIND	6.93 : 1
BIOMASS vs. WIND	5.96 : 1



Alternative	Flexibility
BIOMASS	47.9
WIND	7.22
SOLAR	44.88

Evaluation in context of: Efficiency

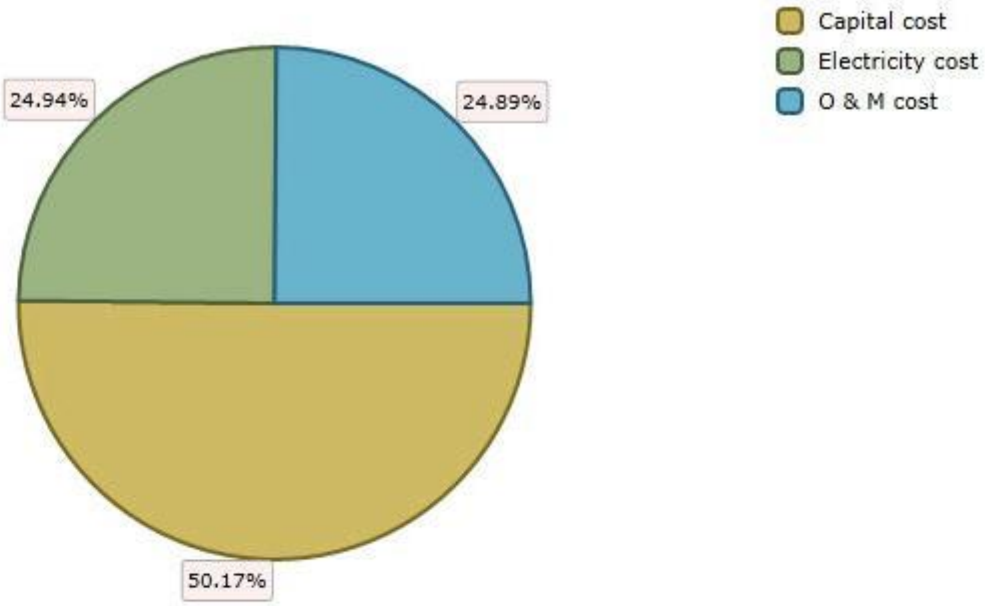
BIOMASS vs. SOLAR	1.41 : 1
SOLAR vs. WIND	6 : 1
BIOMASS vs. WIND	7.67 : 1



Alternative	Efficiency
BIOMASS	53.84
WIND	6.79
SOLAR	39.38

Evaluation in context of: Economical

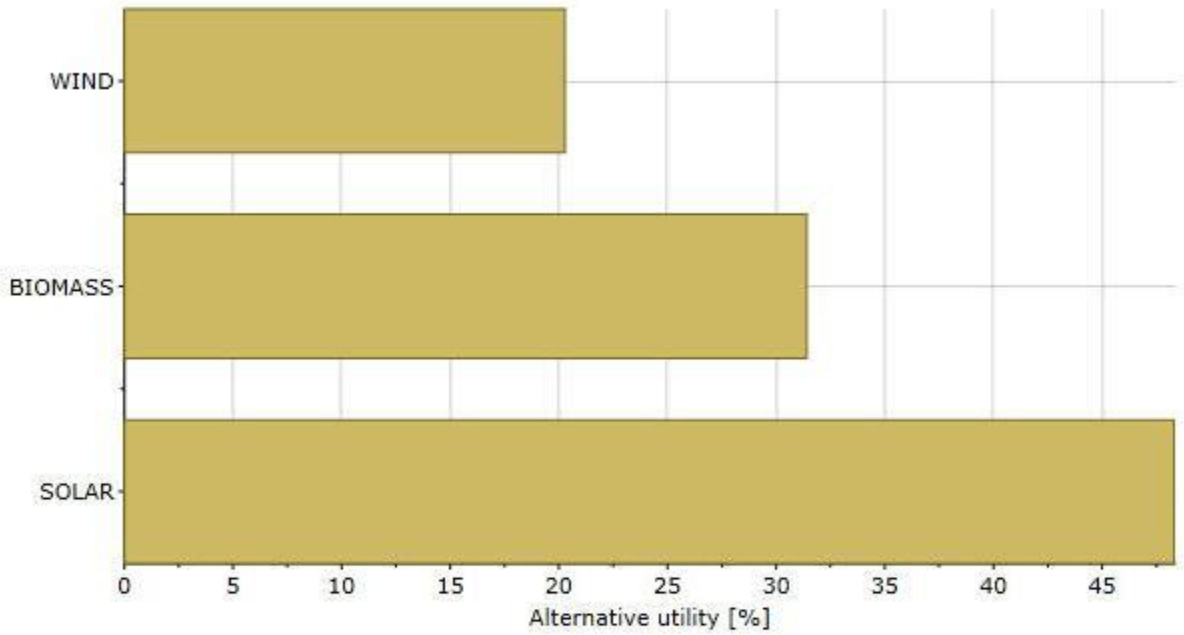
Capital cost vs. O & M cost	1.97 : 1
Capital cost vs. Electricity cost	2.06 : 1
Electricity cost vs. O & M cost	1.03 : 1



Criterion	Weight
Electricity cost	24.94
Capital cost	50.17
O & M cost	24.89

Evaluation in context of: Electricity cost

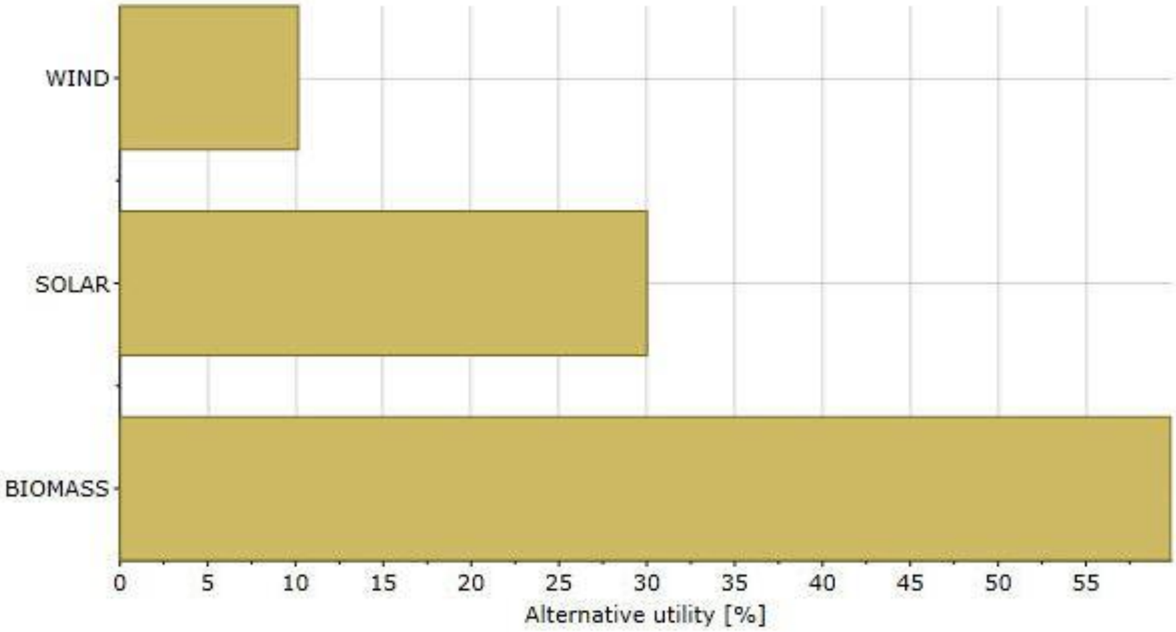
SOLAR vs. BIOMASS	1.5 : 1
SOLAR vs. WIND	2.45 : 1
BIOMASS vs. WIND	1.51 : 1



Alternative	Electricity cost
BIOMASS	31.41
WIND	20.28
SOLAR	48.31

Evaluation in context of: Capital cost

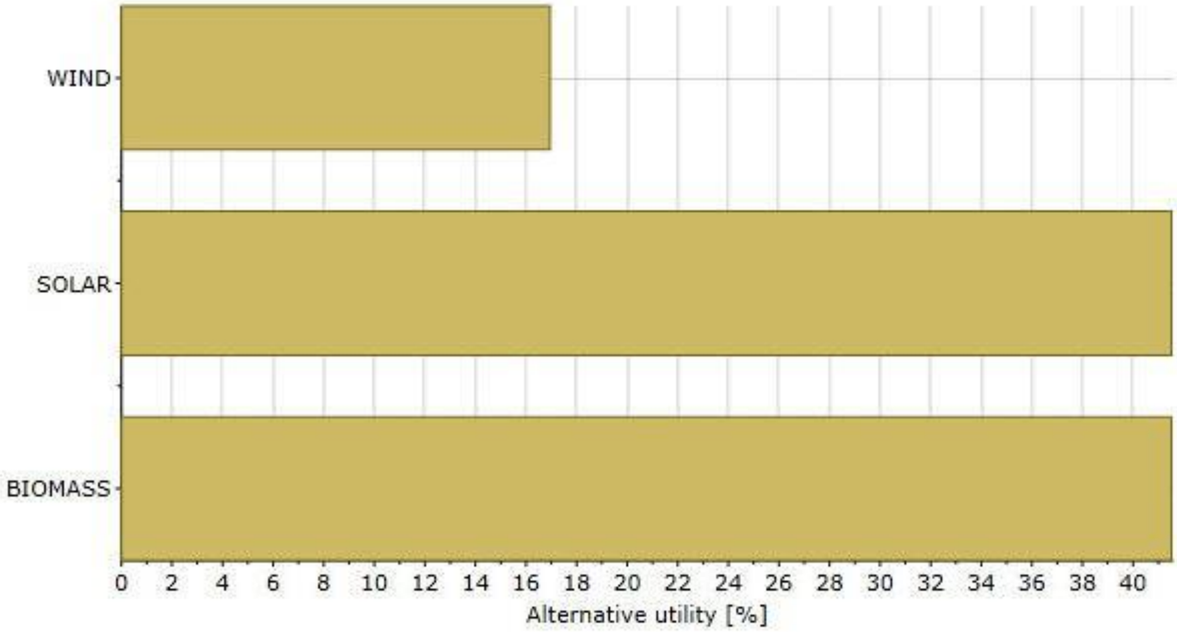
BIOMASS vs. SOLAR	1.97 : 1
SOLAR vs. WIND	2.91 : 1
BIOMASS vs. WIND	5.96 : 1



Alternative	Capital cost
BIOMASS	59.82
WIND	10.17
SOLAR	30.01

Evaluation in context of: O & M cost

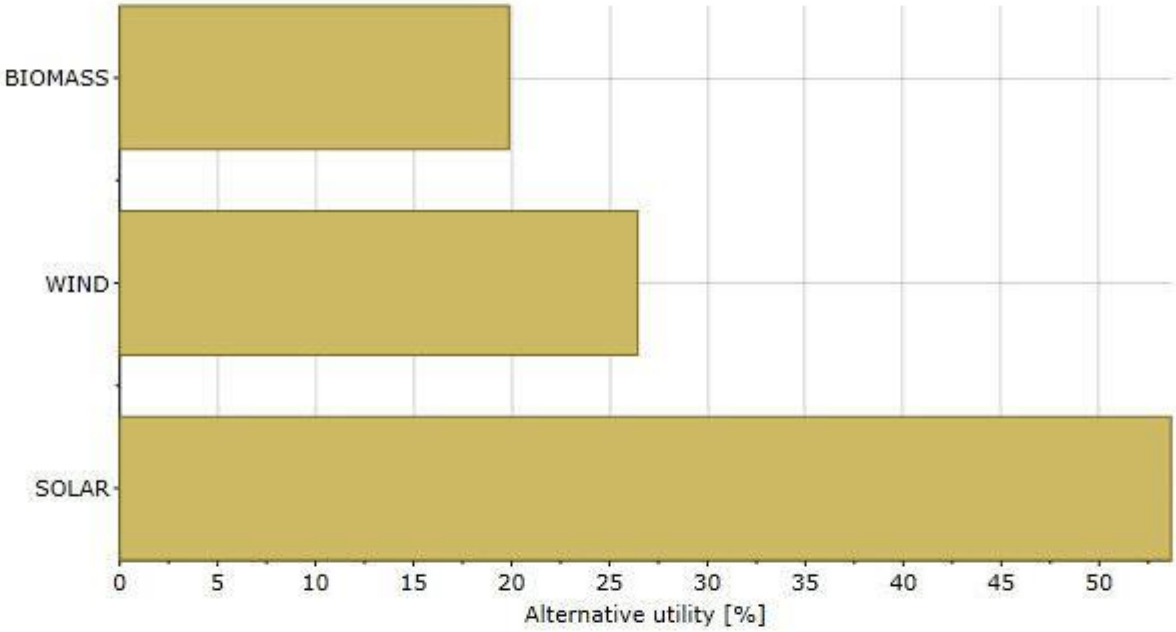
SOLAR vs. BIOMASS	1 : 1
SOLAR vs. WIND	2.45 : 1
BIOMASS vs. WIND	2.45 : 1



Alternative	O & M cost
BIOMASS	41.52
WIND	16.95
SOLAR	41.52

Evaluation in context of: Transport

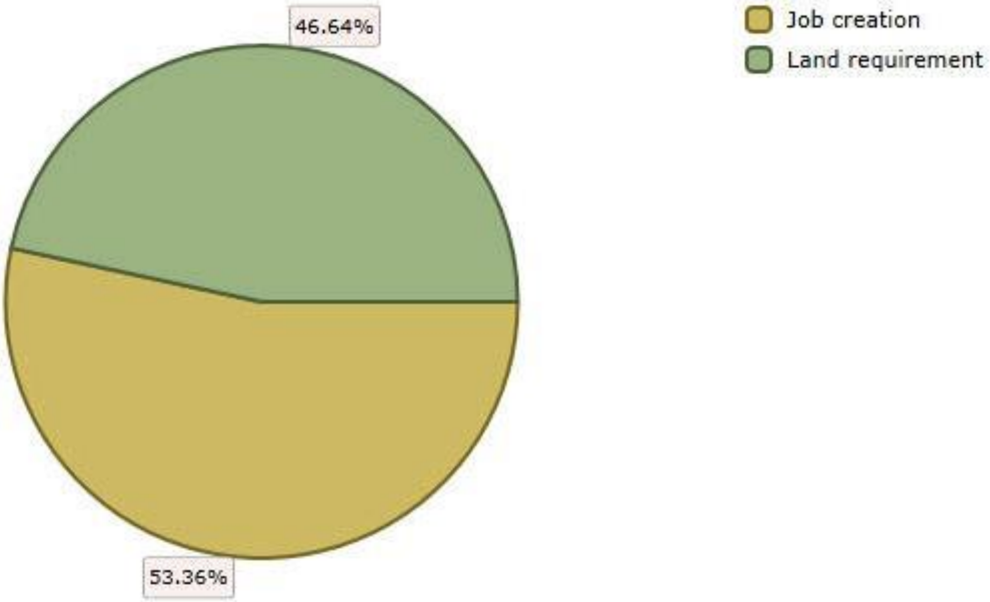
SOLAR vs. BIOMASS	2.66 : 1
SOLAR vs. WIND	2.06 : 1
WIND vs. BIOMASS	1.35 : 1



Alternative	Transport
BIOMASS	19.88
WIND	26.45
SOLAR	53.67

Evaluation in context of: Socio-environmental

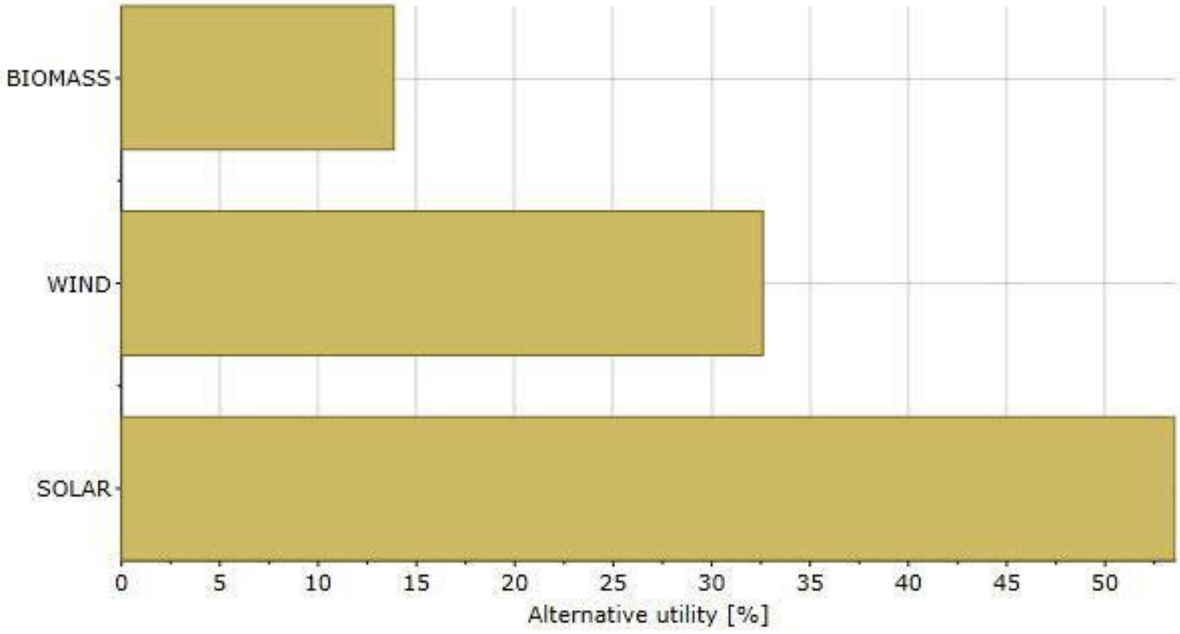
Job creation vs. Land requirement	1.14 : 1



Criterion	Weight
Land requirement	46.64
Job creation	53.36

Evaluation in context of: Land requirement

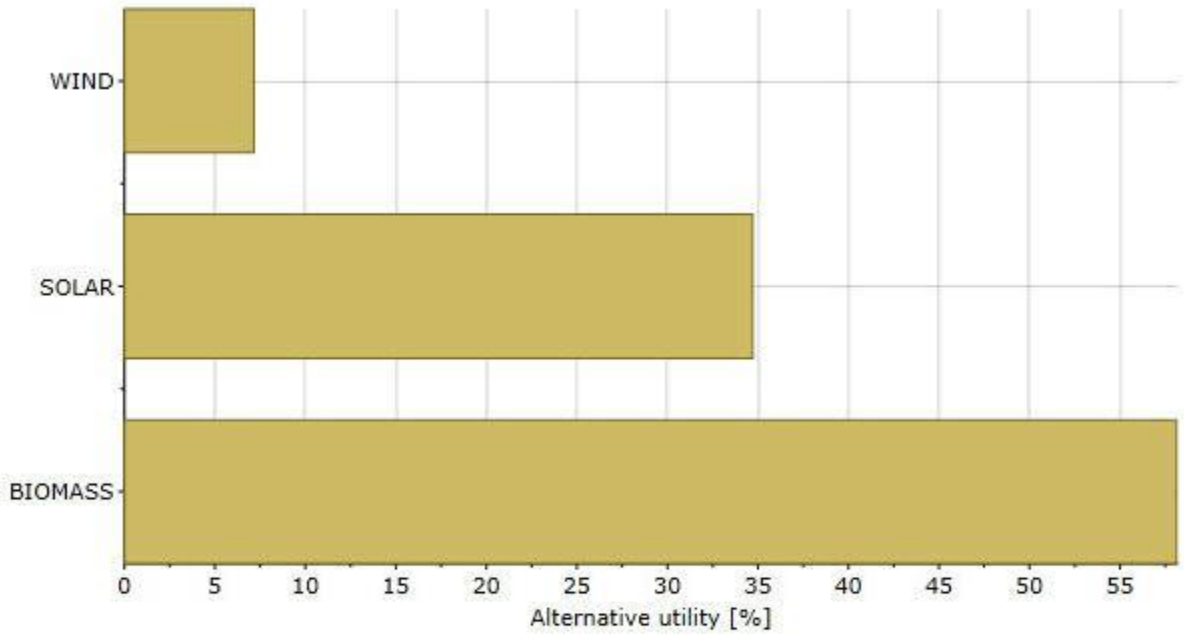
SOLAR vs. BIOMASS	3.66 : 1
SOLAR vs. WIND	1.73 : 1
WIND vs. BIOMASS	2.48 : 1



Alternative	Land requirement
BIOMASS	13.85
WIND	32.61
SOLAR	53.53

Evaluation in context of: Job creation

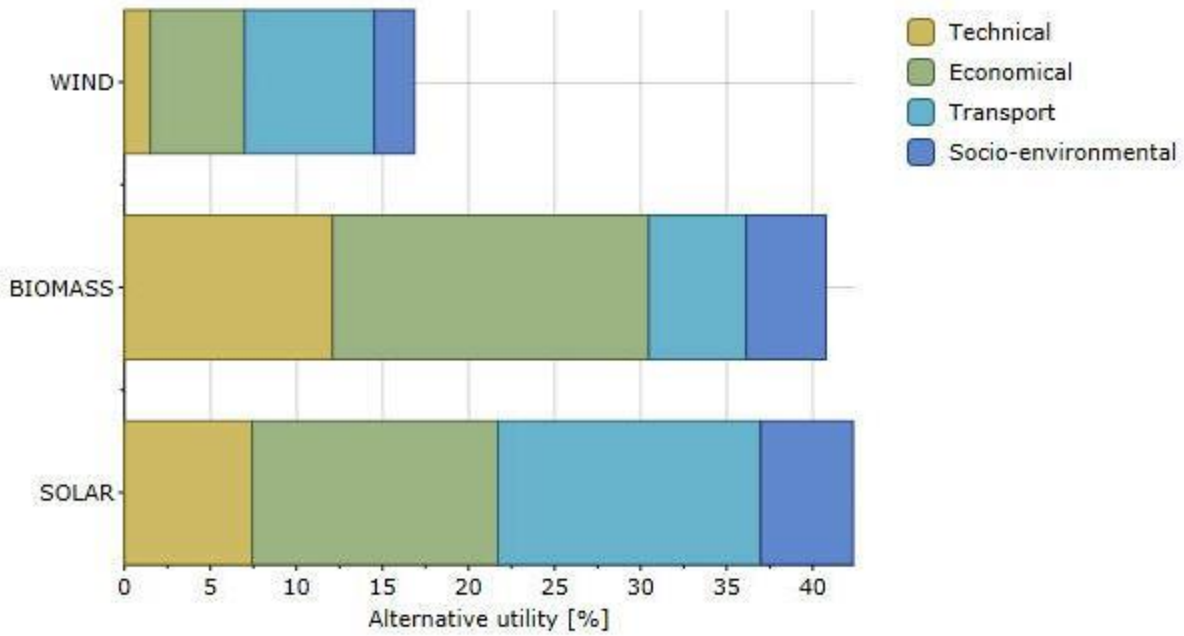
BIOMASS vs. SOLAR	2.06 : 1
SOLAR vs. WIND	5.96 : 1
BIOMASS vs. WIND	6.59 : 1



Alternative	Job creation
BIOMASS	58.12
WIND	7.17
SOLAR	34.71

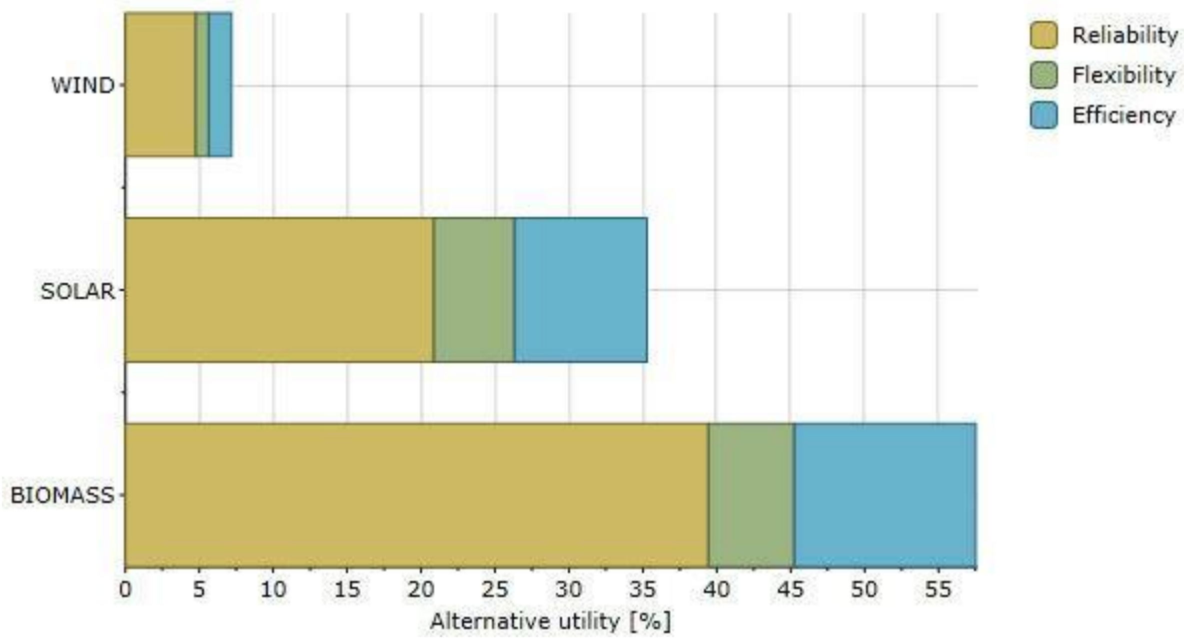
Criterion	Global weight [%]	Local weight [%]
SELECT THE BEST SUITABLE ENRGY SOURCES	100	100
Economical	38.14	38.14
Transport	28.46	28.46
Technical	21.05	21.05
Capital cost	19.14	50.17
Reliability	13.7	65.09
Socio-environmental	12.35	12.35
Electricity cost	9.52	24.94
O & M cost	9.49	24.89
Job creation	6.59	53.36
Land requirement	5.76	46.64
Efficiency	4.8	22.79
Flexibility	2.55	12.12

Ranking in context of: SELECT THE BEST SUITABLE ENRGY SOURCES



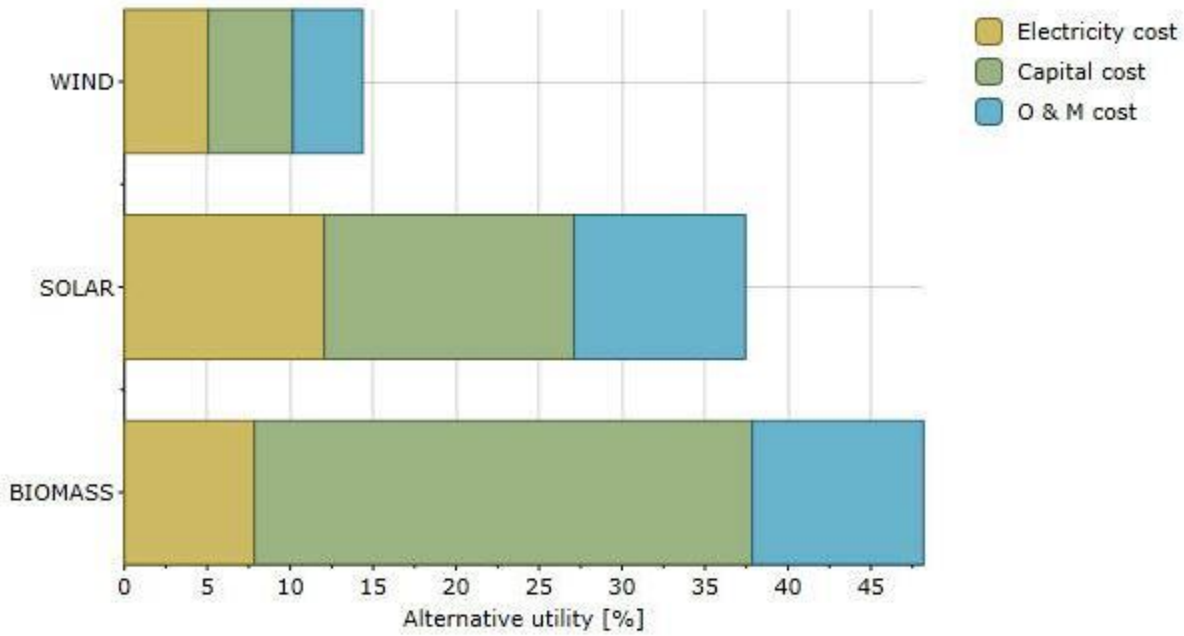
Alternative	Total	Technical	Economical	Transport	Socio-environmental
BIOMASS	40.77	12.1	18.38	5.66	4.63
WIND	16.88	1.51	5.48	7.53	2.35
SOLAR	42.35	7.43	14.28	15.27	5.37

Ranking in context of: Technical



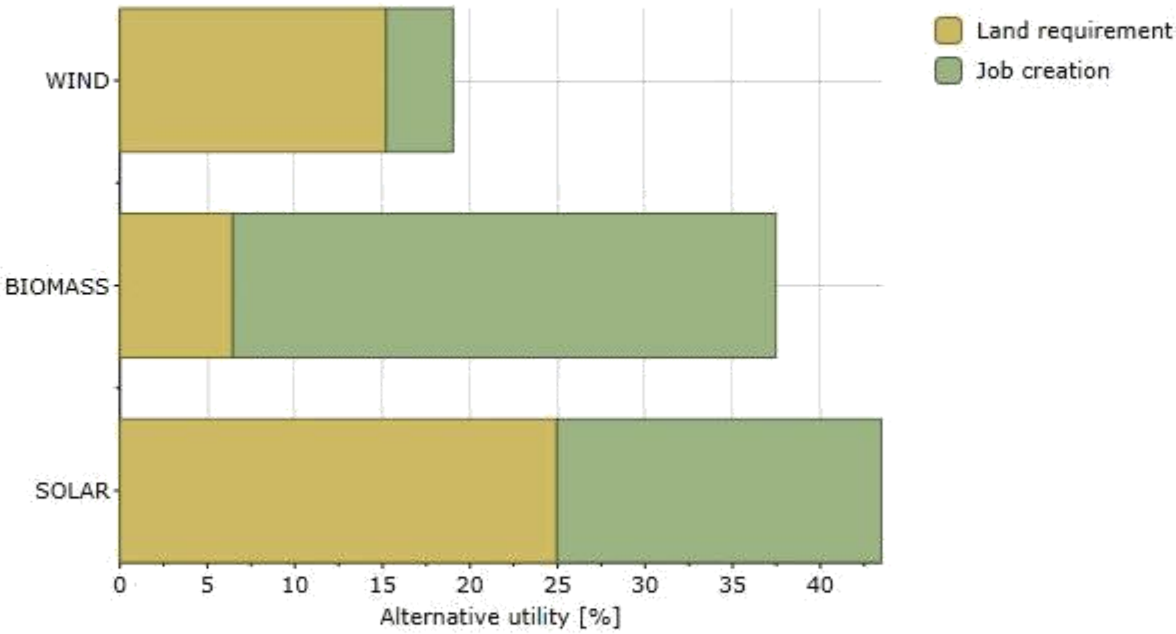
Alternative	Total	Reliability	Flexibility	Efficiency
BIOMASS	57.52	39.44	5.81	12.27
WIND	7.19	4.77	0.87	1.55
SOLAR	35.29	20.88	5.44	8.97

Ranking in context of: Economical



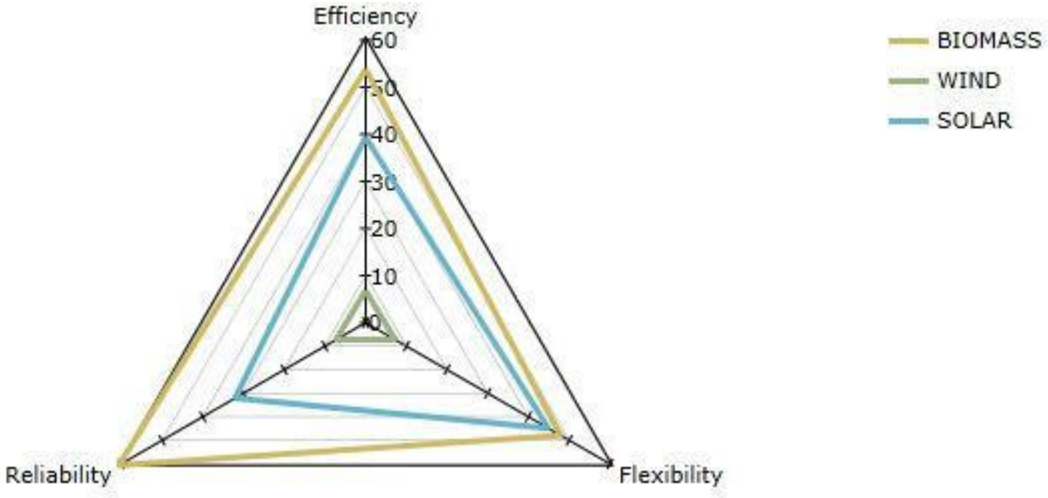
Alternative	Total	Electricity cost	Capital cost	O & M cost
BIOMASS	48.18	7.84	30.01	10.33
WIND	14.38	5.06	5.1	4.22
SOLAR	37.44	12.05	15.06	10.33

Ranking in context of: Socio-environmental


Land requirement
Job creation
WIND
BIOMASS
SOLAR
0
5
10
15
20
25
30
35
40
Alternative utility [%]

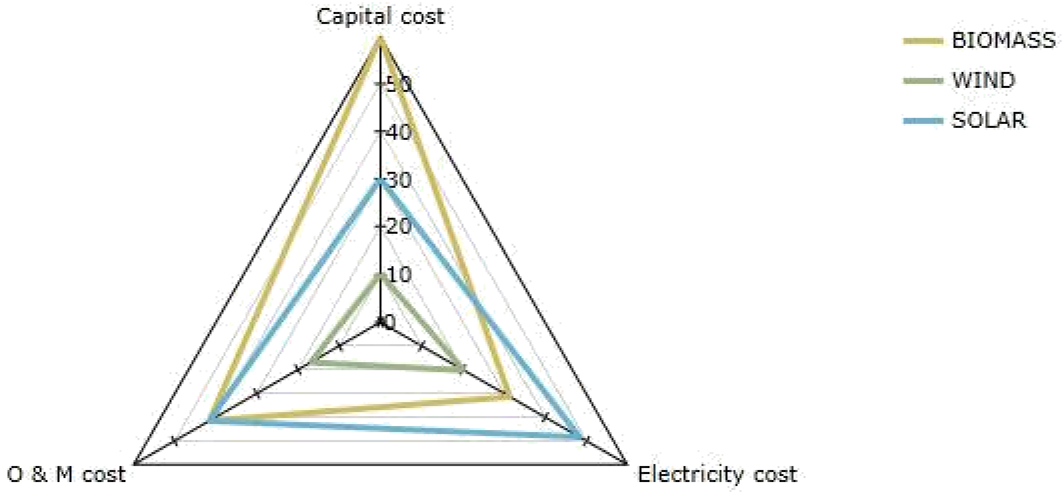
Criterion	BIOMASS	WIND	SOLAR
Technical	57.52	7.19	35.29
Economical	48.18	14.38	37.44
Transport	19.88	26.45	53.67
Socio-environmental	37.47	19.04	43.49

Comparison in context of: Technical



Criterion	BIOMASS	WIND	SOLAR
Reliability	60.6	7.33	32.07
Flexibility	47.9	7.22	44.88
Efficiency	53.84	6.79	39.38

Comparison in context of: Economical



Criterion	BIOMASS	WIND	SOLAR
Electricity cost	31.41	20.28	48.31
Capital cost	59.82	10.17	30.01
O & M cost	41.52	16.95	41.52