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Presented by:

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Multi-Criteria Decision Making for energy planning in Democratic Republic of Congo: case study of Idjwi island

Defended on 03/09/2019 Before the following Committee

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DECLARATION

I, Kamundala Janvier, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here have been fully cited and referenced in accordance with the academic rules and ethics.

Kamundala Janvier

Signed on 02/09/2019

CERTIFICATION

This is to certify that this thesis titled "***Multi-criteria Decision making for energy planning in Democratic Republic of Congo: case study of Idjwi island***" submitted by Kamundala Janvier, Masters student, registration number PAUWES/2017/MEE, in partial fulfillment for the award of Masters in Energy Engineering to the Pan African University Institute of Water and Sciences (Including Climate Change) is a record of bonafide work carried out by him. This thesis has been submitted by my approval as the supervisor

Dr Churchill Saoke

Signed on 02/09/2019

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DEDICATION

This work is dedicated to my lovely wife, Dorcas Kasay for her unconditional love and support and to my two beautiful children Sylvain Kamundala and Ornella Kamundala

ACRONYMS AND ABBREVIATIONS

AHP: Analytic Hierarchy Process

BEBUC: Bourse d'Excellence Bringmann aux Universités Congolaises

CSP: Concentrated Solar Power

DM: Decision Maker

DRC: Democratic Republic of Congo

GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit, The German International Cooperation Agency

GWh: Gigawatts

INS: Institut National de Statistiques

KfW: Kreditanstalt für Wiederaufbau

kW: Kilowatts

MCDA: Multicriteria Decision Analysis (Aids)

MCDM: Multicriteria Decision Making Methods

Mtoe: Megaton oil equivalent

MW: Megawatts

NIS: Negative Ideal Solution

PAUWES: Pan African University Institute of Water and Energy (Including Climate Change)

PIS: Positive Ideal Solution

PV: Photovoltaics

SC: Sub-criteria

SDGs: Sustainable Development Goals

SNEL: Société Nationale d'Electricité

TOPSIS: Technique for Order Preference by Similarity to Ideal Solution

ULPGL: Université Libre des Pays des Grands Lacs

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ABSTRACT

Energy planning involves multiple actors (authorities, community, investors, and operators) and multiple objectives most of the time in perpetual conflict. The Analysis Hierarchy Process (AHP) which consists of a Multi-Criteria Decision Analysis method (MCDA) theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales was used to evaluate the energy resources of Idjwi island in the Democratic Republic of Congo (DRC). The weights obtained from AHP analysis were used to rank the seven alternative energy resources for the island using the Technique of Order Preferences to Similarity to Ideal Solution (TOPSIS). The combination of the two MCDA methods reduces the uncertainty and reinforce the reliability of the decision by combining the advantages of both methods. Two surveys were conducted in this research, one for the rural community in Idjwi, in order to determine their preferences, priority, economic situation for an energy project. The second survey was conducted for the energy experts in the region was to analyse the importance of the criteria. This thesis aims at ranking the different energy resources for rural electrification in the Island. Energy planning in many developing countries is still not well-handled and depend mostly on the priorities of actual authorities. To minimize the risk of investing in wrong sources of energy, energy planning is needed which includes many actors and factors. For example, the exclusion of the local communities in the process of electrification projects can lead to failures of many mini-grid projects in villages. Based on the preferences and priorities of the community, the small hydropower and solar photovoltaic sources were the first alternatives to power Idjwi Island. An assessment of the renewable energy resources of the DRC is also included.

Key words: Multi-criteria Decision Making, AHP, TOPSIS, rural electrification

1. INTRODUCTION

1.1. BACKGROUND

Energy access has been proved in the information age to be inevitable to all kind of development. It has also proven that the 17 Sustainable Developments Goals are interconnected, many scholars agree that the 7th SDG which consists of access to clean energy for all. It can accelerate the other goals such as education, zero hunger, gender equality, etc.

According to the Energy Access Outlook 2017, 1.1 billion people live without access to electricity although remarkable efforts have been made in the past bringing electricity to 1.2 billion people since 2000. The same report showed still 14% of the world population lives without electricity where 84% are in rural areas (IEA, 2017).

In Sub-Saharan Africa, more than 580 million live without electricity compared to 2000 (510 million) (IEA, Energy Access Outlook, 2017). Tremendous efforts have been made to power African countries, for that decentralized and mini-grids have played a key role in electrification of rural areas where the grid solution is expensive (IRENA, 2018).

More than 71 million of Congolese from DRC live without access to electricity, and this represents 12% of the African population (MRHE, 2014). Moreover, according to the INS, 42 million (60% of the DRC population) of the habitants of DRC living without electricity are living in the rural areas (INS, 2015).

The Idjwi Island, located in the East of the DRC in the middle of the Kivu lake, has 250 000 habitants living without electricity. Less than 10% of this population own very small Solar Home Systems (SHS) for lighting. (Azimoh et al., 2016) argued that the mini-grid systems with proper planning and optimization have significant benefits for rural electrification such as the reduction of the cost of electricity production.

A mini-grid is a low voltage electrical grid in which loads, generators and micro sources are operating to supply electricity to rural areas. The mini-grids most of the time use a primary source of renewable energy (solar, hydropower, biogas, biomass, wind, and/or hybrid sources with storage system or diesel generators). These mini-grids can operate autonomously or tied to the main electrical grid. (Hatziargyriou, 2014; IRENA, 2018).

To meet the goals of the initiative of clean energy for all, the 60% of new access to electricity by 2030 will come from renewable energy. Mini-grid using hydro is leading following by solar PV mini-grid technology. The trends need to be scaled up in most African countries (IEA, Energy Access Outlook, 2017; IRENA, 2018). This requires technological, economic solid arguments to attract the investors and advise the policymakers in the national energy plans. The aims of this study are to assess the different barriers and challenges in an engineering approach for Democratic Republic of Congo.

Special attention is required to the mini-grid systems as proved solution to rural communities most of the time with low incomes. Where in another hand the mini-grid imply high investment costs, the high levelized cost of electricity, long payback time, etc. A model including technical, and economic aspects need to be developed from local data collections on existing mini-grids, or in order to design new model.

During the past decades, many countries have deployed projects of mini-grids to assure rural electrification (IRENA, 2018). The viability of such a project differs from one country to another and from a region to another.

DRC has made progress in the liberalization of the Energy sector by promulgating in 2014, the law which regulates the electricity production (Journal Officiel de la RDC, 2014). This liberalization followed by the work of assessment and mapping of energy resources by experts of the ministry of energy in one document to support investors in their decision in order to achieve sustainable energy for all (MRHE, 2014). An optimum power generation mix for rural electrification has not yet been tapped in the current research in DRC. Many options are offering to the country to power the rural community such as the extension of the national grid of SNEL, the large scale deployment of mini-grids with multiplies options like solar mini-grids, hydro mini-grids, biomass mini-grids, hybrid systems mini-grids.

An assessment of resources, technological review and economic analysis on Solar, hydro, biogas, and biomass and hybrid systems were undertaken in this study for the Idjwi Island in DRC, two Multi-Criteria Decision Making methods were selected to choose the best energy alternative for idjwi island.

The population of DRC is growing fast more than 80 million in 2017 (The World Bank, 2018).More than 60% living in rural area (INS, 2015). In another hand, the electricity access rate still low it has increased from 6.48% in 2001 to 9% in 2011 (MRHE, 2014). With exception of the capital city with an electrification rate of 59.5%, the provinces have electrification access below 5% (1% as a national average). (MRHE, 2014).

This work is structured in the following sections. Section I, present the actual renewable resources of DRC, especially for Idjwi Island. The second section describes the multicriteria decision aids method for selecting the suitable energy alternative for Idjwi Island, the MCDM hybrid method using the AHP to determine the weights of the criteria to use in the TOPSIS method (Al Garni, Kassem, Awasthi, Komljenovic, & Al-Haddad, 2016). The last section presents the results from the two MCDM methods used with preferences of experts for electrification of Idjwi Island as an example of the testing the robustness of the framework methodology used in the research.

1.2. PROBLEM STATEMENT AND MOTIVATION OF THE STUDY

In many African countries, DRC included have limited resources for proper planning in the domain of energy. Investors and young entrepreneurs lack results for energy planning. In order to meet the agenda 2030 and the objectives of SE4ALL independent researches in the domain of energy planning and optimization power generation systems to assist decision-makers at all levels are crucial.

Moreover, in order not to violate the inclusivity characteristics of the SGDs (*leave nobody behind*), rural electrification is a key sector that has attracted many researchers in power, energy engineering. In addition, in most politically unstable countries such as DRC, the priority for electrification of different regions can be biased by the political appurtenance, regionalism of leaders, etc. Thus, research in energy planning for rural electrification for a sustainable development based on the actual situation and future scenarios is important for both strategic and operational level. The rural community in DRC represent 69,5% in 2005 and 61,1% in 2012 (MPRM, July 2015), however, the planning and priority are given to urban population leaving a huge amount of the population behind without access to electricity.

The DRC government has committed a delay to release the national energy plan towards 2030 agenda that put the priorities of SDG. The security instability (in the East Beni and in the Central in Kasai) leads the priority of the SDGs in the reinforcement of the security measures and the army. The health challenges such as the Ebola in the East Beni among other challenges that the country is facing have put the energy sector at 8^{th} level in the priority planning (MPSRM, 2016).

1.3. RESEARCH QUESTIONS

This research addressed the following questions:

1. What is the energy scenario of the Democratic Republic of Congo?

2. What is the best method for determining the optimum energy source to electrify Idjwi island?
3. What are the priorities and preferences on energy project for the Idjwi rural community?
4. What are the multi-criteria decision making methods applicable for energy planning in Idjwi island?
5. What is the best method for energy planning in Idjwi island?
6. Using the best method, which alternative source fit to electrify rural community of the Idjwi Island in DRC?

1.4. OBJECTIVES

The objectives of this research are listing as in three main parties as following:

1. To assess the general energy scenario in the Democratic Republic of Congo
2. To investigate the Multi-criteria Decision Making methods for energy planning in DRC
3. To determine the priorities and preferences of the rural community of Idjwi Island on energy projects
4. To determine the preferable source of alternative energy in Idjwi island using the best method for multicriteria decision making method

1.5. METHODOLOGY

In order to address the problem of this research and to meet its objectives the following steps were undertaken

- Data Collection and Data Analysis: Through surveys, interviews, workshops onsite at Idjwi Island, Data was collected to determine the profile load of Idjwi Island, community criteria priority and experts' prioritization of different criteria of selection of the best option among different alternatives of primary energy source.
- Among the Multi-criteria Decision-Making Methods, two methods AHP and TOPSIS were selected for raking of different options of rural electrification of Idjwi Island.
- The results from the previous analyses were used to make a recommendation on the future energy projects at Idjwi Island.

The details of the methodology used in this research are the object of discussion in the following sections.

Technical assessment of different aspects of the energy sector in Idjwi was analyzed. This assessment implied costs and labors intervention such as guides, local community involvement, group discussions and workshops.

1.6. SCOPE OF THE STUDY

This research was limited to mini-grid options for rural electrification, even if in the selection of the option the preferences was defined by the local community of Idjwi Island, experts from the region, local authorities in order to have appropriated mix energy for the Island in the actual context of the country. The energy resources of the countries were presented. However, only the available resources of Idjwi Island were considered in the MCDM for selecting the best mix for Idjwi Island.

The Solar Home Systems and household own power generation system were not addressed in this research. The study focused on the Idjwi Island.

The obstacles that may occur related to this master thesis topic was in a big and diversify country like DRC with a limited number of experts working in the renewable energy the survey to determine the criteria and their importance was complicated.

The availability of some data in the procession of the government agencies like SNEL posed a problem because SNEL had the monopole of the electrification of urban and rural areas in the last 5 decades and for institutional protection did not provide updated data for political reasons.

2. LITERATURE REVIEW AND ENERGY RESOURCES OF DR CONGO

2.1. DEMOCRATIC REPUBLIC OF CONGO CONTEXT

2.1.1. Geography and Climate

The Democratic Republic of Congo, a country of Central Africa, is the second-largest country in Africa after Algeria with the land of 2,345,441, km^2. It is the fourth populated country in Africa with 78,736,153 inhabitants after Nigeria, Ethiopia and Egypt. The country is rich with high energy potential, for example it has the highest hydroelectric potential in the world with 100 GW. However, this huge potential is unexploited. Only 3% of the potential is exploited. As a result, the electrification rate of the country remains among the lowest in Africa at 9% with more than 60 million of its population lives without access to electricity (MRHE, 2014).

The Democratic Republic of the Congo has the second biggest basin in the world: the Congo River Basin, which covers an area of almost 1,000,000 square kilometers. The country's only outlet to the Atlantic Ocean is a narrow strip of land on the north bank of the Congo River.

The Democratic Republic of the Congo (DRC) is bordered by Angola from the southwest, the South Atlantic Ocean, the Republic of Congo, the Central African Republic, South Sudan, Uganda, Rwanda, Burundi, Tanzania across Lake Tanganyika, and Zambia.

The country lies between latitudes 6°N and 14°S, and longitudes 12° and 32°E. It straddles the Equator, with one-third to the North and two-thirds to the South. The size of Congo, 2,345,441 square kilometers, is slightly higher than the combined areas of Spain, France, Germany, Sweden, and Norway.

As a result of its equatorial location, the DRC experiences high precipitation and has the highest frequency of thunderstorms in the world.

The annual rainfall can total upwards of 2,000 millimeters, and the area sustains the Congo Rainforest, the second-largest rain forest in the world after the Amazon. This massive expanse of lush jungle covers most of the vast, low-lying central basin of the river, which slopes toward the Atlantic Ocean in the west. This area is surrounded by plateaus merging into savannas in the south and southwest, by mountainous terraces in the west, and dense grasslands extending beyond the Congo River in the north. High, glaciated mountains (Ruwenzori Mountains) found in the extreme eastern region.

The tropical climate is predominant in the DRC and has also produced the Congo River system which dominates the region topographically along with the rainforest it flows through, though they are not mutually exclusive. The name for the Congo state derives in part from the river. The river basin (meaning the Congo River and all of its myriad tributaries) occupies nearly the entire country and an area of nearly 1,000,000 km^2. The river and its tributaries form the backbone of Congolese economics and transportation. Significant tributaries include the Kasai, Sangha, Ubangi, Ruzizi, Aruwimi, and Lulonga (Encyclopedia, the Democratic Republic of Congo, s.d.).

There are two big seasons in all the country, the rain season (September to April) and the dry season (May to September).

2.1.2. Socio-economic Demographic context

The total population of DRC is 78,736,153, according to the World Bank statistic in 2016 (Bank, s.d.).

According to the Worldometers, this population will be more than 120 million in 2030 (Worldometers, s.d.).

Over 200 ethnic groups populate the Democratic Republic of the Congo, of which the majority are Bantu peoples. Together, Mongo, Luba and Kongo peoples (Bantu) and Mangbetu-Azande peoples constitute around 45% of the population. The Kongo people are the largest ethnic group in the Democratic Republic of Congo (Encyclopedia, the Democratic Republic of Congo, s.d.).

The growth rate of the population in DRC is 3.33% in 2017. 40.2 % of the population live in

Table 1. Population of DRC from 1960 with forecast of 2018

Year	Population	Yearly % Change	Yearly Change	Migrants (net)	Median Age	Fertility Rate	Density (P/Km²)	Urban Pop %	Urban Population	Country's Share of World Pop	World Population	DRC Global Rank
2018	**84,004,989**	3.28 %	2,665,001	23,861	16.8	6.31	37	38.9 %	33,989,753	1.10 %	7,632,819,325	16
2017	**81,339,988**	3.31 %	2,603,835	23,861	16.8	6.31	36	40.2 %	32,712,918	1.08 %	7,550,262,101	17
2016	**78,736,153**	3.33 %	2,539,534	23,861	16.8	6.31	35	40.0 %	31,474,834	1.05 %	7,466,964,280	19
2015	**76,196,619**	3.38 %	2,334,671	3,012	16.8	6.40	34	39.7 %	30,275,467	1.03 %	7,383,008,820	19
2010	**64,523,263**	3.34 %	1,954,357	-8,685	16.9	6.63	28	38.5 %	24,837,538	0.93 %	6,958,169,159	20
2005	**54,751,476**	3.07 %	1,535,018	-48,313	17.0	6.72	24	37.0 %	20,248,430	0.84 %	6,542,159,383	23
2000	**47,076,387**	2.51 %	1,096,129	-201,277	17.2	6.77	21	35.0 %	16,489,579	0.77 %	6,145,006,989	25
1995	**41,595,744**	3.74 %	1,396,233	260,481	17.2	6.77	18	33.2 %	13,796,035	0.72 %	5,751,474,416	27
1990	**34,614,581**	2.98 %	946,227	14,903	17.4	6.71	15	30.9 %	10,694,055	0.65 %	5,330,943,460	29
1985	**29,883,446**	2.54 %	705,197	-89,372	17.5	6.60	13	28.7 %	8,565,179	0.61 %	4,873,781,796	31
1980	**26,357,462**	2.85 %	691,029	20,137	17.7	6.46	12	27.1 %	7,135,507	0.59 %	4,458,411,534	31
1975	**22,902,319**	2.74 %	578,477	5,490	17.8	6.29	10	25.8 %	5,913,521	0.56 %	4,079,087,198	32
1970	**20,009,935**	2.87 %	528,010	48,382	18.1	6.15	9	24.6 %	4,924,015	0.54 %	3,700,577,650	33
1965	**17,369,883**	2.64 %	424,326	0	18.1	5.98	8	23.4 %	4,070,466	0.52 %	3,339,592,688	33
1960	**15,248,251**	2.44 %	346,148	15,000	18.2	5.98	7	22.3 %	3,400,359	0.50 %	3,033,212,527	33

the urban area (32,712,918 people in 2017); the median age is 16.8 years. (Worldometers, s.d.).

Source: Worldometers (www.Worldometers.info)

Elaboration of data by United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2017 Revision. (Medium-fertility variant).

2.1.3. Idjwi Island Demography

Idjwi Island located at 2.1651° S 29.056091 °E rests in Lake Kivu along the border between Rwanda and the Democratic Republic of the Congo (DRC) (Figure 1) in the South Kivu province. At 70 km in length and with an area of 340 km^2, it is the second-largest inland island

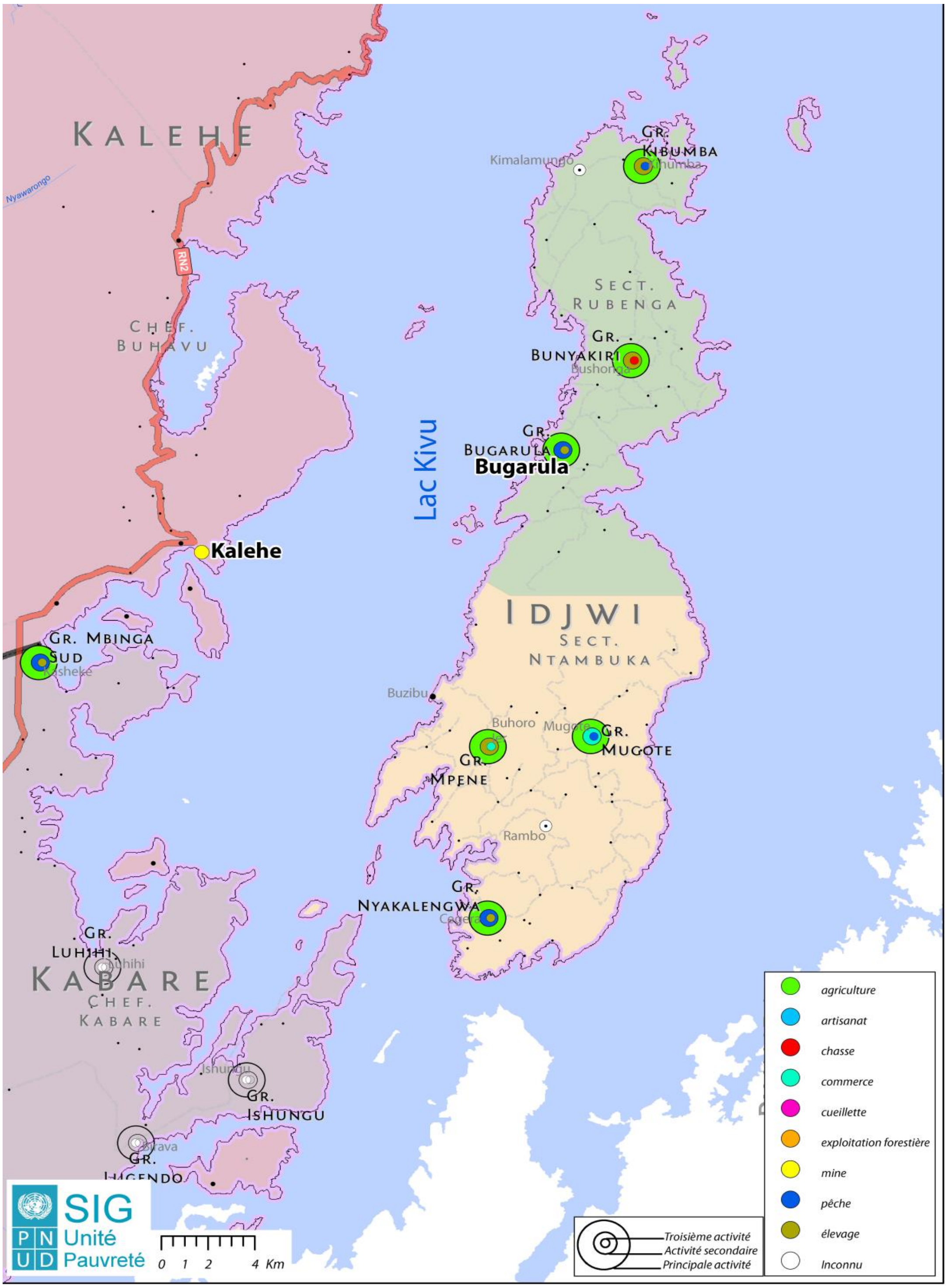

Figure 1. Idjwi Island

in Africa, and the tenth-largest in the world (Wikipedia, s.d.).

Idjwi is composed of two (Chefferies: districts): Ntambuka's cheffery with administrative center, Rambo in the collectivity of Nyakalengwa. The Ntambuka's cheffery has 50 Villages with an estimated area of 186 km^2 and 179626 inhabitants in 2016. The other cheffery of the Idjwi Island is Rubenga with Bugarula as the administrative center in the collectivity of Bugarula. Rubenga's cheffery has 33 villages with an estimated area of 124 km^2 with 118611 inhabitants in 2016 (Rubenga, 2017). Idjwi is located at 75 km far from Bukavu's town and 45 km from Goma by lake. Two tribes live together on the island: Bahavu and Bambuti. The language spoken is the Kihavu.

2.2. RENEWABLE RESOURCES POTENTIALS OF DRC

2.2.1. Hydropower of DRC

The exploitable hydro potential of the whole African continent estimated at ± 1.888.000 GWh/year, of which 774.000GWh concentrated in the Democratic Republic of Congo that is 41% of the total of Africa (Perez, Nkanka, & Ngulumingi, 2005).

Most of this substantial hydro potential of the DRC is in Inga. That is 370,000 GWh/year, 49% of the country's potential, and this is mainly due to the presence of the mighty river Congo (Perez, Nkanka, & Ngulumingi, 2005). The total annual production of hydroelectricity is around 6 000 GWh per year with an installed of 2 516 MW, only 3% of the potential of the country.

Figure 2. Hydropower energy in DRC and hydroelectricity production of the Country

2.2.2. Solar energy

In the DRC, there are some photovoltaic applications, but on a tiny scale (some private). The global horizontal radiation of the country varies between 1200 kWh/m^2 to 2400 kWh/m^2; suitable for PV and CSP applications. The solar potential is shown in the figure 3 below:

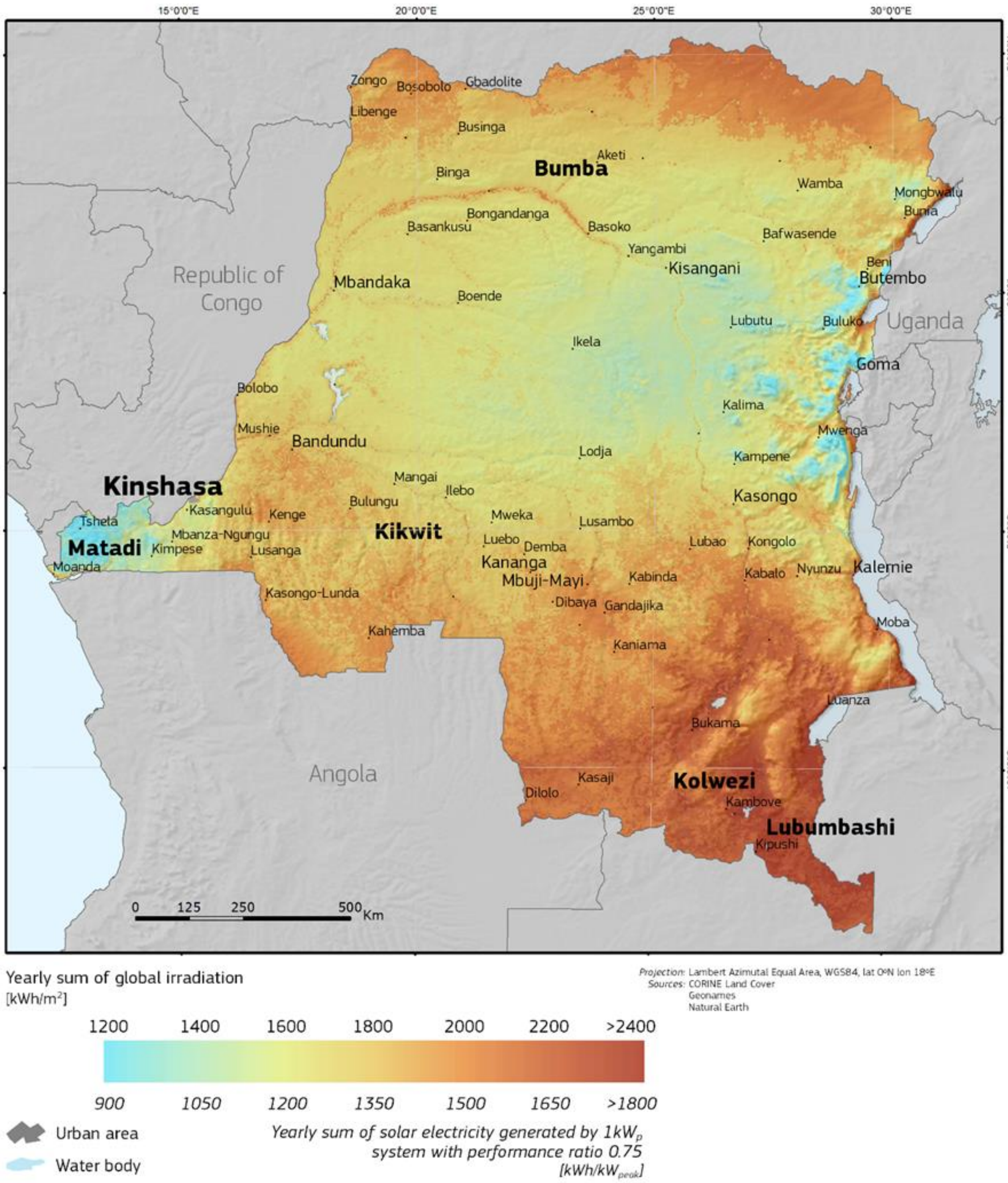

Figure 3. Global irradiation and solar electricity potential of DRC

2.2.3. Bioenergy

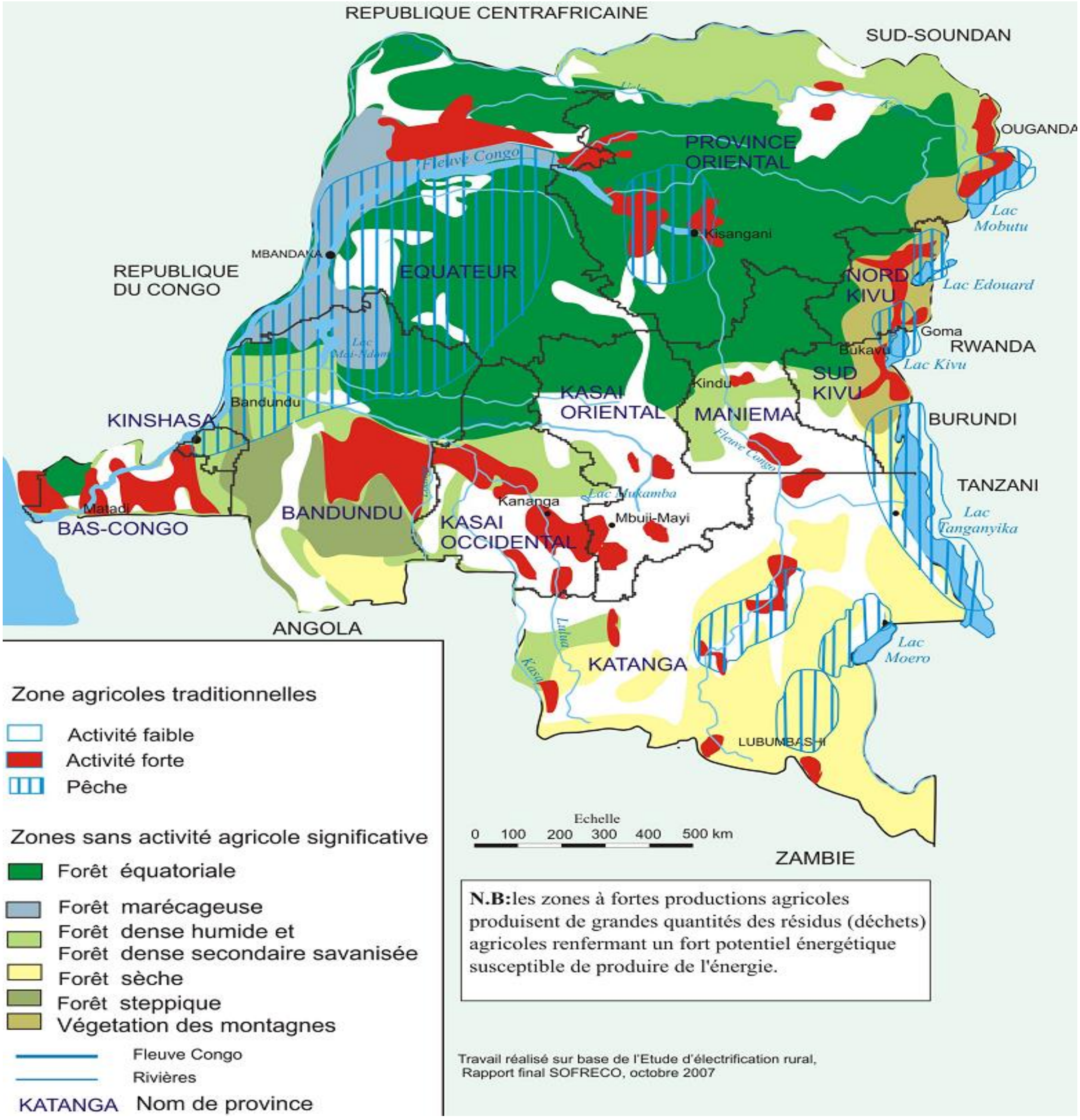

Figure 4.Agricultural zones in DRC

In the DRC, the country is full of several sources of bioenergy. The main one remains the biomass (122 million hectares equivalent to 8.3 billion toes). Indeed, the country has it alone nearly half of all tropical forests on the African continent. Currently, wood (traditional energy source) is the primary source of energy in the country (≈ 92.2 % of energy needs, especially cooking). The biomass is practically not exploited because of the poverty of livestock farming in the DRC (Ndaye, 2015).

Figure 4 above gives the agricultural production of DRC.

2.2.4. Wind energy

In the DRC, there are no wind turbines until today. Some studies conducted by the National Energy Commission (CNE) have shown that the source is not abundant and that its exploitation to produce electricity commercial is not yet possible. These studies concerned the city of Inongo in the Bandundu (the study was done with the support of ITALCON) and the city of Lukolela in Kasaï Oriental (Ndaye, 2015).

On the other hand, the average wind speed taken at 2 m from the ground (over 24 hours in m / s) in many cities of DRC is less than 5 m/s (speed required for starting a wind turbine).

2.2.5. Geothermal energy

In the DRC, geothermal opportunities are located in the east and south-east of the country, particularly in the volcanic region between lakes Kivu and Tanganyika. It should be noted that the DRC was the first African country to produce electricity in from geothermal energy: during the 1950s, a copper mine from the Katanga region produced several hundred kilowatts from a 90ºC source. (Ndaye, 2015).

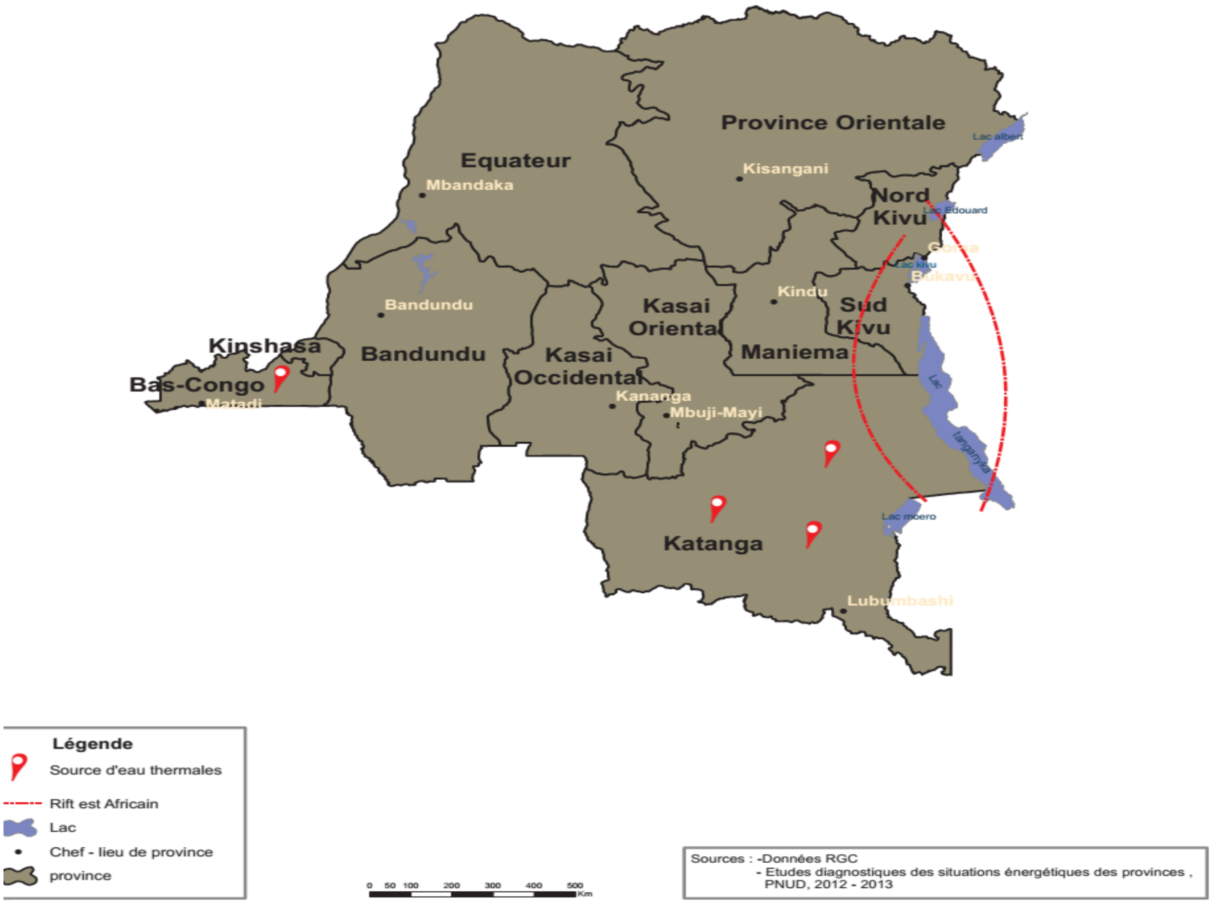

Figure 5. Geothermal potential of DRC *(MRHE, 2014)*

2.3. ENERGY PRODUCTION

In general, the Democratic Republic of the Congo has reserves of petroleum, natural gas, coal, and a potential hydroelectric power generating capacity of around 100,000 MW shown previously. The Inga Dam, alone on the Congo River, has the potential capacity to generate 40,000 to 45,000 MW of electric power, sufficient to supply the electricity needs of the whole Southern Africa region. Ongoing uncertainties in the political arena and a resulting lack of interest from investors has meant that the Inga dam's potential has been limited (Kansal, Gupta, Farrukh, & Mulé, 2015) (encyclopedia, s.d.).

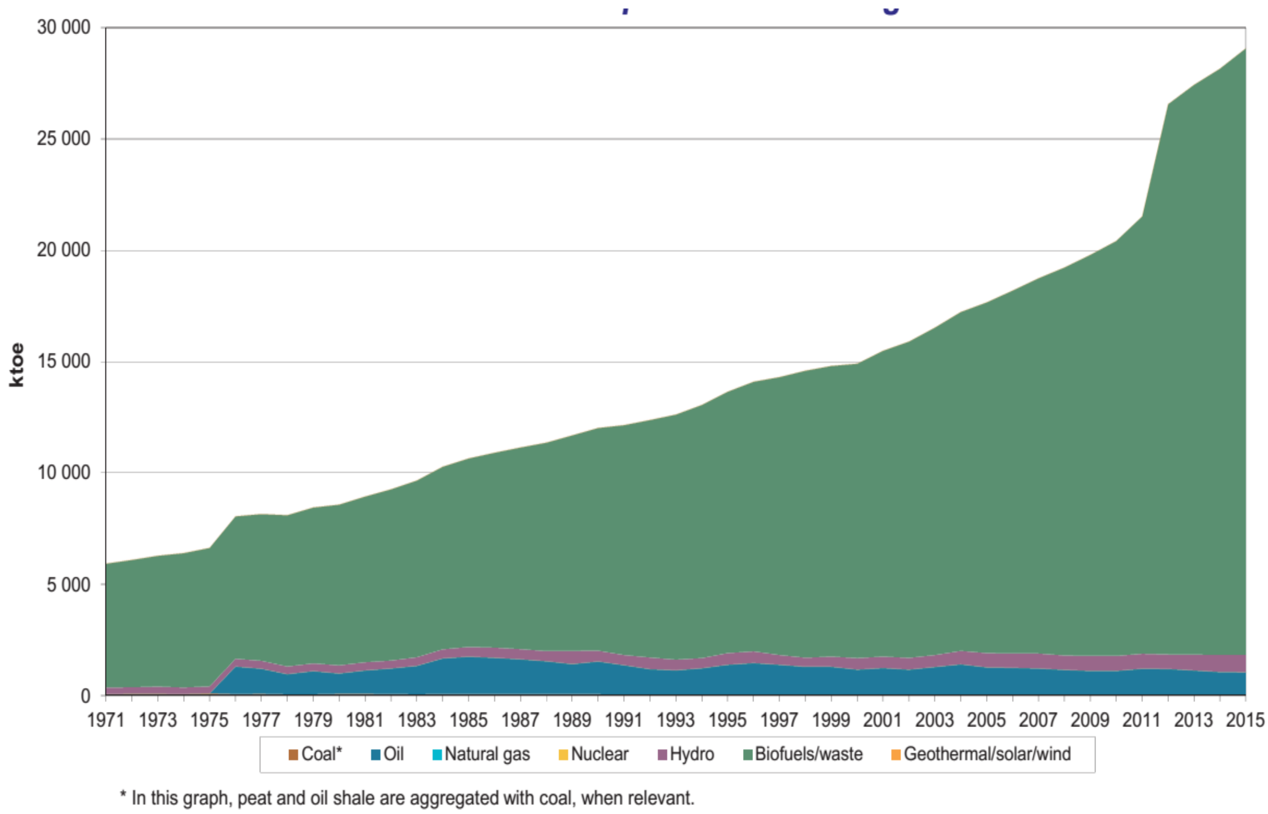

Figure 6. Energy production of DRC from 1971 to 2015 *(IEA, s.d.)*

In 2012, the dam was estimated to have an installed generating capacity of 2,473 MW (Ndaye, 2015). There are plans to raise the Inga power station to 44,000 MW. The African Development Bank has agreed to supply $8 million towards it (encyclopedia, s.d.). The government has also agreed to strength the Inga-Kolwezi and Inga-South Africa interconnections and to construct a second power line to supply power to Kinshasa.

Table 2. Electricity production of DRC by primary energy sources

	Electricity
Production from:	*Unit: GWh*
- coal	0
- oil	12
- gas	4
- biofuels	10
- waste	0
- nuclear	0
- hydro*	8916
- geothermal	0
- solar PV	0
- solar thermal	0
- wind	0
- tide	0
- other sources	0
Total production	8942

For the national electrification rate, it increased from 6.48% in 2001 to 9% in 2011. However, with the exception of Kinshasa (59.5%) and Bas-Congo, other Provinces are below 5% (1% as a national average) (MRHE, 2014).

Most of the electricity in DRC is produced from hydroelectric sources with a tiny portion

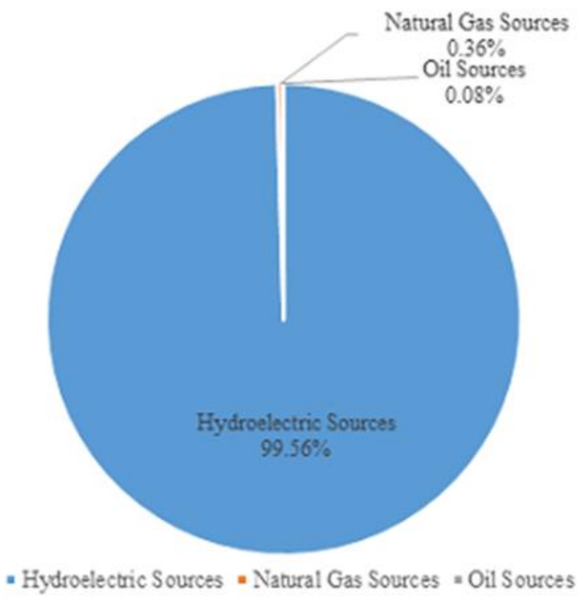

Figure 7. DRC Electricity production by sources

coming from natural gas and oil, as shown in Figure 7.

2.4. ENERGY CONSUMPTION

In DRC, just over 93.3% of the total consumption of energy comes from biomass (wood fire, charcoal and waste), while other forms of energy contribute at a rate of only 4.1% for petroleum products and 2.6% for electricity.

The energy consumption in DRC can be split as in the table 3:

Table 3. DRC Energy consumption by sector

Sector.	Electricity Demand (GWh)	Pecentage of Total Demand
Household	21248.62	98.1%
Industrial	418.42	1.931%
Transport	0.00394	0.00002%
Commercial	0.01996	0.00009%
Total	23319.568	100%

The total electricity consumption in the last decade has increased by 57%, mainly due to an increased percentage of the population with access to electricity. Currently only 16.4% of the population has access to electricity in DRC, which hints at increased electricity consumption in the coming years.

The electricity is consumed in the following sector below:

2.4.1. Household

The total energy demand in the households in DRC in 2012 was 21.248 Mtoe. This demand was further split into Urban and Rural in the following manner.

Table 4. Household Energy consumption in urban and rural area

Sector.	Electricity Demand (GWh)	Pecentage of Total Demand
Urban	6.125	28.8%
Rural	15.123	71.2%
Total	22.9113	100%

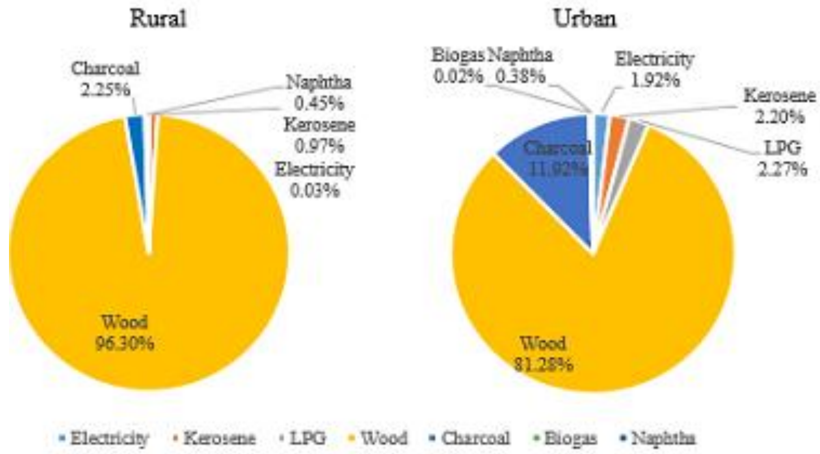

Figure 8. DRC Urban and Rural Household Energy Demand by fuel

The household electricity demand of DRC in 2012 was 2,262GWh, which corresponds to 31.8% of the total electricity demand in 2012. The household electricity demand can also further be divided into Urban and Rural.

Out of the total 16.4% electrified population, 55.7% of the rural population and 36.31% of the urban population has access to electricity, as can be seen in Figure 9.

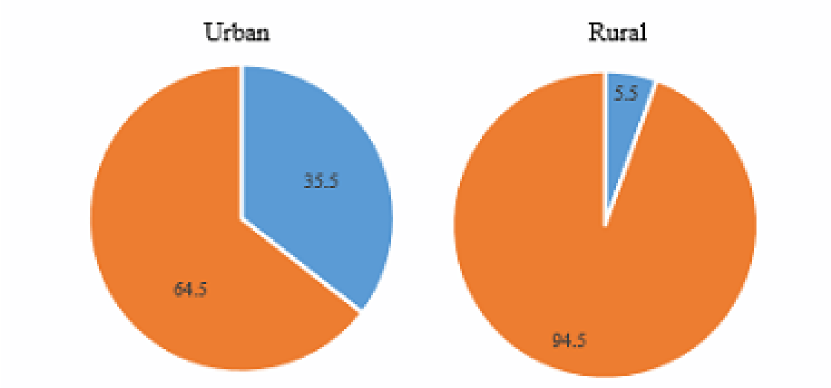

Figure 9. Pourcentage of Electrified households

The energy demand in the households has been categorized into cooking, refrigeration, lighting, and other uses.

2.4.2. industry

The industrial sector in DRC is the largest consumer of energy after households. The total energy demand by the industrial sector was 418.41ktoe. Table 5 shows the demand split into various subsectors.

Table 5. DRC Industrial Energy Consumption by Sector

Sector.	Electricity Demand (GWh)	Pecentage of Total Demand
Agriculture and Forestry	280.846	67.12%
Mining and Quarrying	61.65181	14.73%
Energy and Water	16.81413	4.02%
Manufacturing	28.02355	6.70%
Construction	31.08067	7.43%
Total	418.41617	100%

The industrial electricity demand in 2012 accounted for 65.38% of the total demand. The significant economic activity in the country was fueled by agriculture and mining industry, accounting for 39.4% and 12.1% of the GDP respectively. Construction, manufacturing and trading contributed to the rest of energy demand. (IEA, The Energy production of Democratic Republic of Congo, s.d.).

2.4.3. Commercial

The commercial sector had an energy consumption of only 19.961 Toe in 2012, which corresponds to 0.00009% of the total energy demand in DRC. The electricity demand in the commercial sector was just 2.9% of the total, which accounted for a mere 208GWh. The electricity demand was primarily for the lighting purposes in the urban commercial areas. On the other hand, rural commercial lighting needs were wholly met by kerosene oil (Kansal, Gupta, Farrukh, & Mulé, 2015).

2.4.4. Transportation

Similar to the commercial sector, the transport sector in the DRC also has a deficient energy demand. This is primarily because of underdeveloped transportation infrastructure and lack of economic activity in the region. Out of the total energy demand, almost 99% of the consumption is by the passenger transport. In both freight and passenger transport, water transport consumes the most amount of energy followed by road transport (Kansal, Gupta, Farrukh, & Mulé, 2015).

Table 6. DRC Consumption by transport type

Sector.	Electricity Demand (GWh)	Pecentage of Total Demand
Freight	3.895	99.00%
Passenger	0.0389	1.00%
Total	3.93504	100%

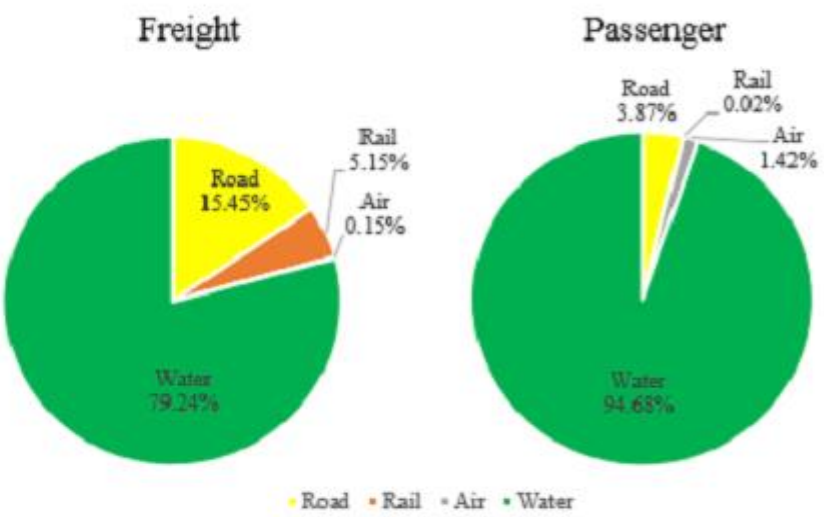

Figure 10. Energy Demand in Transport Sector

2.5. THEORY OF MULTI CRITERIA DECISION ANALYSIS (AIDS) METHODS

The term multiple criteria decision analysis (MCDA) refers to various methods developed for aiding decision-makers in reaching better decisions. The reason for using 'Decision Aid' or 'Decision Analysis' instead of 'Decision Making' in many kinds of literature is to emphasize that the method should aid the Decision Makers (DMs) in making better decision, the methods themselves cannot make the actual decisions. These methods are divided into three main groups:

5. Value measurement models, goal, aspiration
6. Reference level models
7. Outranking models (Loken, 2007).

These methods are based on weighted averages, priority setting, outranking, fuzzy principles and their combinations can be employed for energy planning. One of the main objectives is to estimate the future demand of a region. Many applications are using the MCDA methods as given in (Strantzali & Aravossis, 2016). Among them:

8. Energy Policy and Management: the aim of this application is to evaluate the energy systems with the purpose of guiding the development and formulation of the energy policy.
9. Environmental Impact Analysis: the purpose here is to focus on environmental issues for the energy use. The decision methods are supporting on minimizing the environmental impact and evaluate whether the environmental standards are followed.
10. Electrical network planning: it deals with strategic planning issues on power generation, transmission and distribution such as expansion planning, etc.
11. Evaluation of power generation technologies and projects: it includes evaluation and selection of energy technologies and appraisal of energy investment projects
12. Regional and National planning for the coverage of energy demand

The following section describes shortly the MCDA methods mostly used in the literature (Kumar A. , et al., 2017):

1. **Analytic Hierarchy Process (AHP)/ Analytic Network Process (ANP)**: Developed by Saaty (Saaty T. L., 2004). The Analytic Hierarchy Process (AHP) and its generalization to dependence and feedback, the Analytic Network Process (ANP), are theories of relative measurement of intangible criteria. With this approach to relative measurement, a scale of priorities is derived from pairwise comparison measurements only after the elements to be measured are known. In the AHP paired, comparisons are made with judgments using numerical values taken from the AHP absolute fundamental scale of 1–9. A scale of relative values is derived from all these paired comparisons, and it also belongs to an absolute scale that is invariant under the identity transformation like the system of real numbers. AHP is widely used for practical MCDA method in various domains, in addition to energy systems. The ANP is a generalization of the Analytic Hierarchy Process. The basic structures are networks. Priorities are established in the same way they are in the AHP using pairwise comparisons and judgments. The AHP/ANP are useful for making multi-criteria decisions involving benefits, opportunities, costs and risks.

The AHP is a flexible and intuitive method for decision-makers, which also calculates the consistency of the judgments of the experts. Several studies demonstrate the relevance of this method in energy planning projects with renewable energies (Algarín, Llanos, & Castro, 2017; Al Garni, Kassem, Awasthi, Komljenovic, & Al-Haddad, 2016).

2. **The technique for order preference by similarity to ideal solutions (TOPSIS):** The basic concept of this method is that the selected alternative should have the shortest distance from the negative ideal solution in a geometrical sense. The method assumes that each attribute has monotonically increasing or decreasing utility. This makes it easy to locate the ideal and harmful ideal solutions. Thus, the preference order of alternatives is yielded by comparing the Euclidean distances (Pohekar & Ramachandran, 2004). The ideal alternative has the best level for all criteria, whereas the negative ideal is the one with all the worst criteria values (Kaya & Kahraman, 2011).

3. **Multi-attribute Utility Theory (MAUT)**: this method takes into consideration the decision maker's preferences in the form of the utility function which is defined over a set of attributes. The utility value can be evaluated by determination of single-attribute utility functions followed by verification of preferential and utility independent conditions and derivation of multi-attribute utility functions (Pohekar & Ramachandran, 2004).

4. **MCDA combined fuzzy methodology**. The classic MCDA methods generally assume that all criteria and their respective weights are expressed in crisp values, and thus, that the rating and the ranking of the alternatives can be carried out without any problem. Due to the availability and uncertainty of information as well as the vagueness of human feeling and recognition, it is relatively difficult to provide exact numerical values for the criteria, make an exact evaluation and convey the feeling and recognition of objects for decision-makers. The combination of MCDA methods and fuzzy set theory has been applied in many systems in addition to energy systems. In this context, a realistic approach is the use of linguistic variables in the process of the different methods, which are composed of a finite set of linguistic terms and their meaning is a fuzzy subset in a universe of discourse.

5. **The outranking methods**: **ELECTRE** and **PROMETHEE**. Compared to the other multi-criteria evaluation methods, the outranking methods have the characteristic of allowing incomparability between alternatives. The Elimination and Choice Translating Reality (ELECTRE) concentrates the analysis of the dominance relations among the alternatives. The basic concept is how to deal with outranking relation by using pair-wise comparisons among alternatives under each criterion separately. The Preference ranking organization method for enrichment evaluation (PROMETHEE) uses the outranking principle to rank the alternatives, combined with the ease of use and decreased complexity. Like to ELECTRE method, it also performs a pair-wise comparison of alternatives in order to rank them with respect to a number of criteria. However, ELECTRE method only pays attention to the preference and ignore the difference level between alternatives when determining the ranking order. PROMETHEE introduces the preference functions to measure the difference level between alternatives when determining the ranking order. Nevertheless, it is useful to compare the results from each method and in the case of coinciding rankings, the reliability of the assessment procedure is considerably strengthened (Polatidis, Haralambopoulos, Munda, & Vreeker, 2006).

The list above about the MCDA methods is not exhaustive, and other methods are used depending on the domain and the preference of the DMs. Velsquez and Hester summarized the MCDA methods, their advantages, disadvantages and areas of application in table 7 below

Table 7. Summary of MCDM Methods

Method	Advantages	Disadvantages	Areas of Application
Multi-Attribute Utility Theory (MAUT)	Takes uncertainty into account; can incorporate preferences.	Needs a lot of input, preferences need to be precise	Economics, finance, actuarial, water management, energy management, agriculture
Analytic Hierarchy Process	Easy to use, scalable, hierarchy structure can easily adjust to fit many sized problems, not data intensive.	Problems due to the interdependence between criteria and alternative can lead to inconsistencies between judgment and ranking criteria, rank reversal	Performance-type problems, resource management, corporate policy and strategy, and planning
The technique for Order preferences by Similarity to Ideal Solution (TOPSIS)	Has a simple process, easy to use and program, the number of steps remains the same regardless of the number of attributes	Its use of Euclidean Distance does not consider the correlation of attributes, difficult to weight and keep the consistency of judgment.	Supply chain management and logistics, engineering, manufacturing systems, business and marketing, environmental, human resources, and water resources management
Simple Additive Weighting (SAW)	Ability to compensate among criteria, intuitive to decision-makers, calculation is simple does not require complex computer programs	Estimates revealed do not always reflect the real situation, the result obtained may not be logical.	Water management, business, and financial management
PROMETHEE	Easy to use, does not require the assumption that criteria are proportionate	Does not provide a clear method by which to assign a weight	Environmental, hydrology, water management, business and finance, chemistry, logistics and transportation, manufacturing and assembly, energy, agriculture
ELECTRE	Takes uncertainty and vagueness into account	Its process and outcome can be difficult to explain in layman's terms; outranking causes the strengths and	Energy, economics, environmental, water management, and transportation problems.

		weaknesses of the alternative to not be directly identified.	
Goal Programming (GP)	Capable of handling large-scale problems, can produce infinite alternatives	It's the ability to weight coefficients typically needs to be used in combination with other MCDM methods to weight coefficients.	Production planning, scheduling, health care, portfolio selection, distribution systems, energy planning, water reservoir management, scheduling, wildlife management
Simple Multi-Attribute Rating Technique (SMART)	Simply allows for any type of weight assignment technique, less effort by decision-makers	The procedure may not be convenient considering the framework	Environmental, construction, transportation and logistics, military, manufacturing and assembly problems.
Fuzzy Set theory	Allows for imprecise input, takes into account insufficient information	Difficult to develop, can require numerous simulations before use.	Engineering, economics, environmental, social, medical, and management
Data Envelopment Analysis (DEA)	Capable of handling multiple inputs and outputs; efficiency can be analyzed and quantified.	Does not deal with imprecise data; assumes that all input and output are exactly known.	Economics, medicine, utilities, road safety, agriculture, retail, medical, and management
Case-Based Reasoning (CBR)	Not data-intensive; requires little maintenance; can improve over time; can adapt to changes in environment	Sensitive to inconsistent data; requires many cases.	Businesses, Vehicle insurance, medicine, and engineering design.

The methodological framework used in this work combined two methods of MCDM: AHP and TOPSIS, the following sections detail the two methods.

2.6. OVERVIEW OF AHP-TOPSIS APPROACH

The aim of selecting the AHP-TOPSIS method is because AHP determines the weights of the criteria, and the alternatives are ranked using TOPSIS (Afsordegan, Sánchez, Agell, Zahedi, & Cremades, 2016). AHP-TOPSIS methods follows the following procedures as explained by the number of researches conducted in Multicriteria Decision Making Method (Wan, Yan, Zhang, Shi, & Fu, 2014; Kumar, He, Deng, & Kumar, 2016; Lee & Chang, 2018; Soufi, Ghobadian , Najafi, Sabzimaleki, & Yusaf, 2015). “The main weaknesses of TOPSIS are that it does not deliver for weight elicitation, and consistency checking for judgments; on the other hand, the use of AHP has been significantly restrained by the human capacity for the information process” (Roszkowska, 2011).

2.6.1. AHP Method

AHP involves the decision architects to provide judgments and specify preferences on the relative importance of each criterion and each alternative considering all criteria. In AHP, the problem is created as a hierarchy breaking down the decision top to bottom. “The goal is at the top level, criteria and sub-criteria are in middle levels, and the alternatives are at the bottom layer of the hierarchy (Daim, Oliver, & Kim, 2013). The following are the essential steps to be followed in AHP model:

a) Construct a Comparison Matrix

Construct a matrix from a pairwise comparison of criteria using a well defined scale of relative importance as proposed by Saaty in table 8 (Saaty T. L., 2008). The scale presented was proposed and its effectiveness has been approved by numerous scholars. Obtained pairs of criteria A_i and A_j are represented by an $n \times n$ single-value comparison matrix A:

$$A = a_{ij} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}$$

Where, a_{ij} is the relative importance of criteria A_i and A_j (Daim, Oliver, & Kim, 2013).

Table 8. The fundamental scale of absolute numbers

Intensity of importance	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	

5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
1.1-1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities

b) Calculate the Importance Degree of each Element

Set priorities for criteria, a numerical value must be assigned to all criteria according to the preferences of the DM.

The weighting vector of a specific element k can be calculated through the following Equation:

$$W_k = \frac{1}{n}\sum_{j=1}^{n}\left(a_{kj}/\sum_{i=1}^{n} a_{ij}\right) \quad (k = 1,2,\ldots\ldots,n) \tag{1}$$

Where, a_{ij} is the entry of row i and column j in a comparison matrix of order n, and W_k is the weighting vector of a specific element k in the pairwise comparison matrix.

c) Consistency Test

Check the consistency of the matrix before the results. The comparisons is considered reasonable only if the consistency ratio is equal to or less than 0.10 (Siksnelyte, Zavadskas, Streimikiene, & Sharma, 2018; Velasquez & Hester, 2013; Wimmler, Hejazi, Fernandes, Moreira, & Connors , 2015). An approximation of the ratio can be obtained using the following equation;

$$CR = \frac{CI}{RI} \tag{2}$$

While

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{3}$$

Where CR is the consistency ratio, RI is the random index, λ_{max} is the maximum weighting value of an n×n comparison matrix. Table 9 shows the random Index value for different matrices sizes as identified by Daim, Oliver and Kim (Daim, Oliver, & Kim, 2013).

Table 9. Average Random Index (RI) Values

Matrix size (n)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

2.6.2. TOPSIS Method

TOPSIS refers to Technique of Order Preference by Similarity to Ideal Solution, this method considers three types of attributes or criteria which are; Qualitative benefit attributes or criteria, quantitative benefit attributes and Cost attributes or criteria. The key idea of TOPSIS is to assess the alternatives by concurrently measuring how far are they from the Positive Ideal Solution (PIS) and to the Negative Ideal Solution (NIS) i.e. through distance measure (Sarraf, Mohaghar, & Bazargani, 2013; Soufi, Ghobadian , Najafi, Sabzimaleki, & Yusaf, 2015). TOPSIS assumes that we have m alternatives (options) and n attributes/criteria and we have the score of each option with respect to each criterion. Let x_{ij} be the score of option i with respect to criterion j, we have a matrix X = (x_{ij}), m × n matrix. Let J be the set of benefit attributes or criteria (more is better) and let J' be the set of negative attributes or criteria (less is better). The following are the procedures to be followed when performing TOPSIS.

The matrix X that consists of the original information is shown as equation (4).

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{4}$$

a) *Construct Normalized Decision Matrix.*

This step aims at transforming various attribute dimensions into dimensionless attributes to allow comparisons across criteria from different sources. This is carried out as follows where r_{ij} are the normalized values;

$$r_{ij} = \frac{x_{ij}}{\sqrt{\left(\sum x_{ij}^2\right)}} \tag{5}$$

For i=1,…, m; j=1,…,n.

b) *Construct the weighted normalized decision matrix.*

Assume we have a set of weights for each criteria w_j for j = 1,…, n. Multiply each column of the normalized decision matrix by its associated weight.

An element of the new matrix is:

$$v_{ij} \ = \ w_j * r_{ij} \tag{6}$$

c) *Determine the ideal and negative ideal solutions.*

Assume J the set of benefit attributes or criteria more is better and let J' be the set of cost attributes or criteria less is better.

Positive Ideal solution

$$A^+ \ = \ \{v_1^+, \dots, v_n^+\} \tag{7}$$

Where

$$v_i^+ = \left\{\max_i(v_{ij})\ if\ j \in J; \min_i(v_{ij})\ if\ j \in J'\right\}$$

Negative ideal solution

$$A^- \ = \ \{v_1^-, \dots, v_n^-\} \tag{8}$$

Where

$$v_i^- = \left\{\min_i(v_{ij})\ if\ j \in J; \max_i(v_{ij})\ if\ j \in J'\right\}$$

d) *Calculate the separation measures for each alternative*.

The separation from the ideal alternative is

$$S_i^+ = [\sum_i (v_j^+ - v_{ij})^2]^{1/2} \quad (9)$$

i = 1, …, m

Similarly, the separation from the negative ideal alternative is:

$$S_i^- = [\sum_i (v_j^- - v_{ij})^2]^{1/2} \quad (10)$$

i = 1, …, m

e) *Calculate the relative closeness to the ideal solution C_i*

$$C_i = \frac{S_i^-}{(S_i^- + S_i^+)} \quad (11)$$

Whereby $0 < C_i < 1$. Select the option with C_i closest to 1

The best option among the alternatives is the one with the highest value of C_i.

3. RESEARCH METHODOLOGY

To achieve the objectives of this research, selection of suitable energy alternative for powering Idjwi Island, the following steps were used as developed by Kumar and al in (Kumar, He, Deng, & Kumar, 2016; Kumar , et al., 2018)

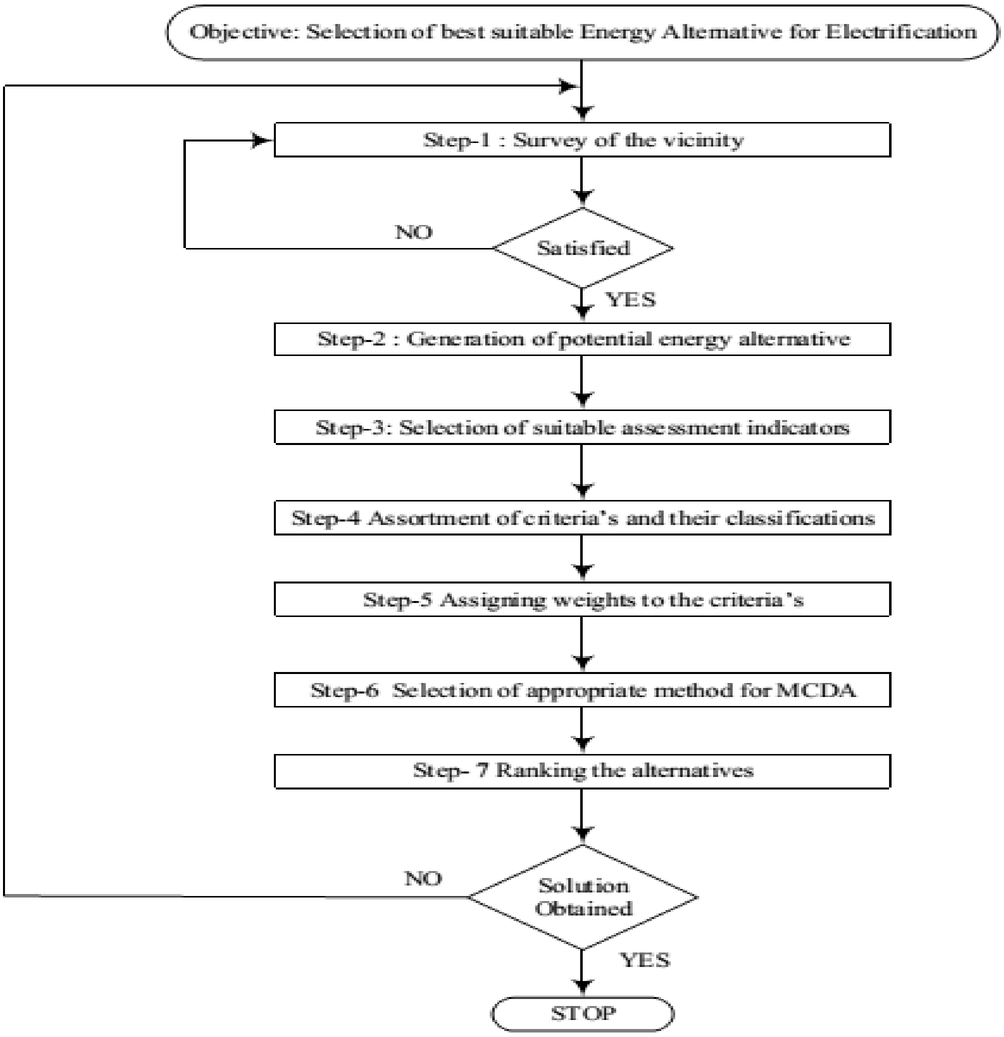

Figure 11. Methodological Framework for selection of energy alternative

As illustrated in the figure 11, the generalized framework for selecting a suitable and reliable rural energy source for developing countries. From the results of two surveys, one for the rural community and another one for experts in the energy sector, we used this methodological framework of seven different steps as shown in the figure 11 to meet the objective of selecting a suitable solution for energy projects in Idjwi. Step 1 is a series of survey to determine the preferences of local community and experts. This was done using surveys attached in the Appendix 1. Step 2 of generation of potential energy alternatives that we have done on chapter two and the summary of available energy resources of Idjwi is given at the figure 13 below. Step 3 is based on the results of the step 1 in order to fix criteria based on judgement and views of decision-makers and experts. This was done using a survey (see Appendix 2) to specify which criteria and sub-criteria to use for evaluation of the different alternatives. The table 10 below gives the maintained criteria according to preferences of the actors interviewed. The following step was handling by AHP method in order to assign weight to different criteria and sub-criteria. This process reported in the section of results and discuss for every criteria and sub-criteria. The last step ranked the different alternatives using TOPSIS method. This step used the available data from Idjwi and in the literature to analyse the different alternatives to power Idjwi. This is reported in the section results and discussion of this thesis.

3. 1. SURVEYS DESIGN

A door to door survey of a targeted 67 households with a questionnaire was carried out in the rural community of Idjwi (See Appendix 1). A set of meetings and workshops were also conducted with local authorities, academics, experts in the energy sector of the region. The purpose of these initiatives during this research was based on the recommendations of similar researches (Kumar, He, Deng, & Kumar, 2016) in the same domains in order to convince the local community to be part of an electrification project of the Island. More objectives were to:

13. Understand the community's support towards the energy project
14. The energy demand assessment of the Idjwi Island
15. The financial situation of the community to get the average income of a household per month to pay for the electricity bill
16. Evaluate the availability of the resources which can be utilized and possible sites for implementing the project

Another survey was distributed to the experts in the energy sector (see Appendix 2) in order to select different criteria and sub-criteria to use in the AHP and TOPSIS methods. This survey was also conducted to question the preferences of the experts on the criteria considering the social and economic situation of the inhabitants of Idjwi.

Energy planning is a field that involves many aspects, actors and multiple attributes both qualitative and quantitative which cannot evaluate by a single-phase evaluation indicator such as Cost to Benefit Analysis (CBA) or Net Present Value (NPV). Planning in energy technologies involves a multidimensional problem with multiple objectives and many traits (Kumar , et al., 2018; Al Garni, Kassem, Awasthi, Komljenovic, & Al-Haddad, 2016; Bhardwaj, Joshi, Khosla, & Dubash, 2019). This involvement of multiple stakeholders, benchmarks, and more energy alternatives (renewable and non-renewable) sources in rural electrification system has made the design process more complex. Various MCDM models have been developed for energy planning for electrification purpose to reach sustainability. A detailed review of such models and their application has been elaborated by authors as reported above in the literature review of this thesis and in (Kumar A. , et al., 2017). Scientific methods such as MCDM which involve the evaluation of both qualitative and quantitative attributes to rank different types of energy resources over a long period (time) dimensions have become popular (Al Garni, Kassem, Awasthi, Komljenovic, & Al-Haddad, 2016). Many actors including groups of people in the local community, institutions and administration authorities, potential investors, academic institutions, environmental agencies are stakeholders in MCDM and define the main criteria to be considered.

This study involved four criteria proposed by the experts in the energy sector with carefully selected sub-criteria (both qualitative and quantitative) under different dimension units to facilitate the ranking of energy technologies in Republic Democratic of Congo through MCDM techniques. Researchers have recommended to combine or compare two methods in order to reduce uncertainty and to increase the reliability of the methods (Trotter, McManus, & Maconachie, 2017). That is the reason why AHP was used in order to determine different weights of the criteria and sub-criteria. It was followed by a TOPSIS method for evaluating the best solution to power Idjwi Island. Figure 12 indicates different steps that were taken during this thesis by developing a hybrid method of Multi-criteria decision making AHP-TOPSIS to rank different alternatives for energy resources.

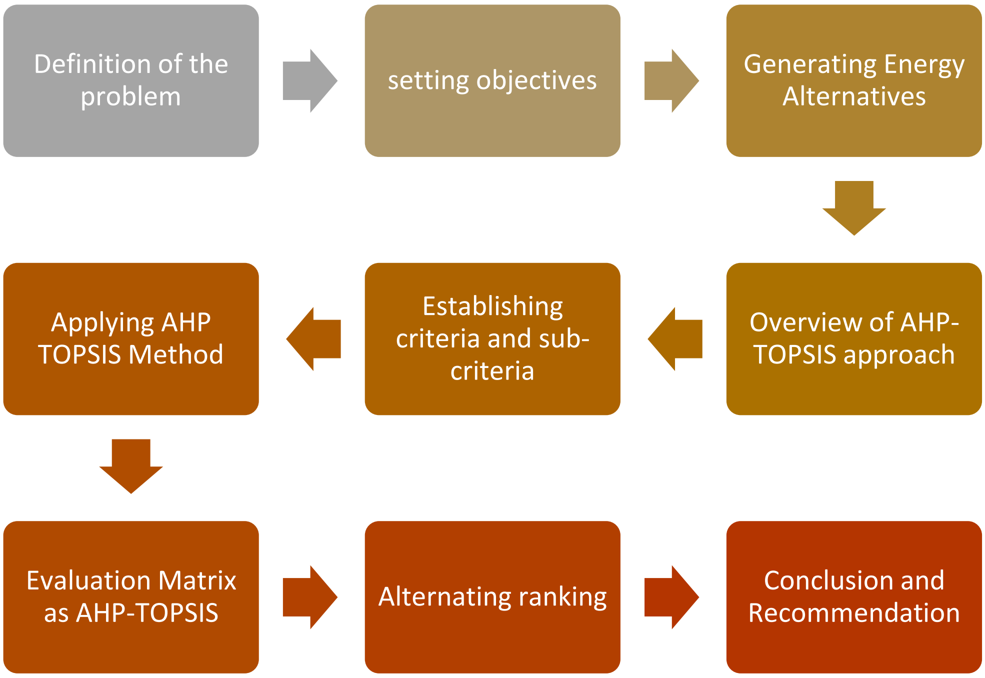

Figure 12. A proposed methodology using AHP-TOPSIS in MCDM for DRC

This section elaborates the steps from the flow diagram in figure 12

3.2. DEFINING THE PROBLEM AND GOALS

The Democratic Republic of Congo is the second largest country of Africa after Algeria with a population estimated to more than 80 million in 2018. Only 12% of the population lives with access to electricity and more than 71 million left without electricity. For more than three decades, political instability has put the country in difficult situation to establish proper energy policies to embrace renewable utilization. The country has the highest potential of hydroelectricity in Africa and many other renewable energy resources such as solar, geothermal, etc. However, the lack of energy planning and policy has made the development of energy business not progressive as in neighbor countries like Rwanda and Uganda where there are many deployments of renewable mini-grid system. After the liberalization of the sector of energy in DRC in June 2014 and the publishing of the Atlas of renewable energy by the ministry of electricity, many private investors have started to develop mini-grid and energy systems. Thus, assistance on decision making on which source of energy to use is still necessary for future investors. This study focuses on the energy planning for rural electrification of Idjwi Island. It consists of determining the best solution to power the rural areas of DRC using a case study of Idjwi.

3.3. GENERATING ENERGY ALTERNATIVES

Since DRC is still using Hydroelectricity at large and it will continue using large hydro by 2030 despite the fact that a diversified energy mix is preferable for energy security, then this work evaluated both Fossils and Renewable energy sources of Idjwi and ranked them depending on their common attributes. The figure 13 below shows the seven alternatives available in Idjwi Island in DRC: These alternatives were obtained from different reports of the local authorities, NGOs documents and government reports and onsite visit during the field trips at Idjwi (MRHE, 2014; Rubenga, 2017).

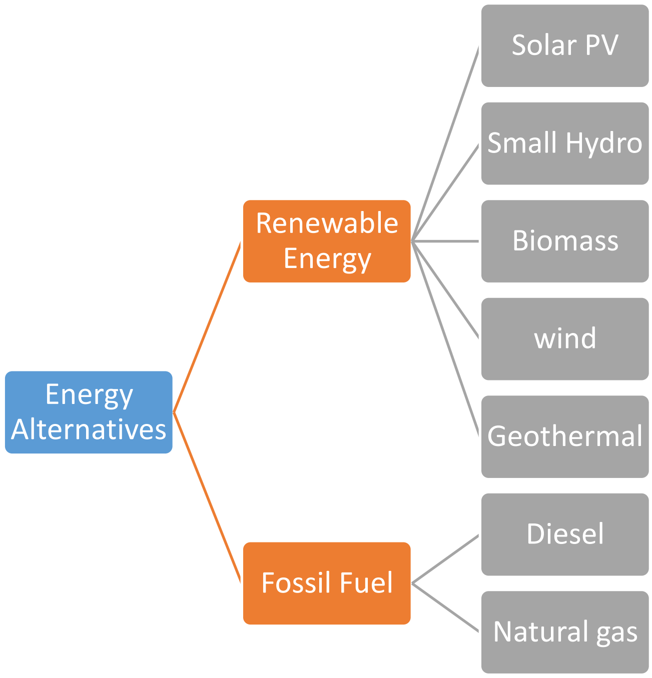

Figure 13. Energy Alternatives of Idjwi Island in DRC

3.4. ESTABLISHING CRITERIA AND SUB-CRITERIA

Many scholars have proposed a set of criteria and sub-criteria that are mostly used in the selection of sustainable energy alternatives (Al Garni, Kassem, Awasthi, Komljenovic, & Al-Haddad, 2016; Algarín, Llanos, & Castro, 2017; Bhardwaj, Joshi, Khosla, & Dubash, 2019; Kumar , et al., 2018). A list of these criteria was submitted to a group of experts from academics in Goma (the main city of North Kivu), companies working in the renewable energy sectors, agents from the national company of electricity of DRCongo, (SNEL) and local authorities from the Idjwi island, and to Non-governmental organization (Association de Soutien aux Initiatives de Développement d'Idjwi, ASAIDI) in a form of a questionnaire (See Appendix 2) to select the most urgent according to the actual context of Idjwi Island. After compilation of the results from the survey, the following four criteria and 17 sub-criteria of the table 10 were maintained following the preferences of the actors consulted: A list of references used to establish and supported these criteria is given per sub-criterion in the same table 10.

Table 10. Maintained Criteria and sub-criteria for Idjwi context

Criteria	Notation	Sub Criteria	References
Technical	SC_1	Energy availability	(Wang, Jing , Zhang, & Zhao, 2009; Amer & daim, 2011; Ahmad & Tahar, 2014; Akash, Mamlook, & Mohsen, 1999; Mateo, 2012; Theodorou, Florides, & Tassou, 2010; Stein, 2013; Zhang, Lu, & Liu, 2014);
	SC_2	Efficiency	
	SC_3	Energy System Safety	
	SC_4	Technology Maturity	
Environmental	SC5	CO_2 emissions	(Ahmad & Tahar, 2014; Daim, Oliver, & Kim, 2013; Kumar , et al., 2018; Zhang, et al., 2015; Mateo, 2012; Shen, Lin, Li, & Yuan, 2010; Gumus , Yayla, Celik, & Yildiz, 2013)
	SC_6	SO_x emissions	
	SC_7	NO_x emissions	
	SC_8	Land Requirement	
	SC_9	Impacts on ecosystems	
Economic	SC_{10}	Capital Cost	(Wang, Jing , Zhang, & Zhao, 2009; Zhang, Lu, & Liu, 2014; Kaya & Kahraman, 2011; Hirmer & Cruickshank, 2014; Kahraman, Kaya, & Cebi, 2009; Kahraman, Cebi , & Kaya, 2010)
	SC_{11}	O&M cost	
	SC_{12}	Economic development	
	SC_{13}	Externality Cost	
	SC_{14}	Levelized Cost of Electricity (LCOE)	
Social	SC_{15}	Job creation	(Al Garni, Kassem, Awasthi, Komljenovic, & Al-Haddad, 2016; Daim, Oliver, & Kim, 2013; Kaya & Kahraman, 2011; Kahraman, Kaya, & Cebi, 2009; Kumar , et al., 2018; Wan, Yan, Zhang, Shi, & Fu, 2014)
	$SC1_{16}$	Social acceptance	
	SC_{17}	Impact on Health	

4. RESULTS ANALYSIS AND DISCUSSION

4.1. WEIGHTS OF CRITERIA

The AHP method was first used to determine the weights of all criteria and sub-criteria established by the results of the surveys, interviews, meetings and workshops. The main reasons for selecting AHP was its simplicity, flexibility and its ability to handle both quantitative and qualitative criteria in the same framework (Loken, 2007).

The scenario considered in this work comes from the survey's results and is presented as follows

17. Social criteria were the most important in the four criteria considered because the community is living in a condition of extreme poverty with an average of one America Dollar per day. For this reason, in the scale of pairwise comparison proposed by Saaty (Saaty T. L., 2004),
18. The technical criteria come after the social criteria because for the sustainability of the project, a trained team for maintenance and operating the micro-grid.
19. The economic and environmental criteria follow to have the scenario below:
    Social Criteria > Technical Criteria > Economic Criteria > Environmental Criteria

Table 11 reports the different weights of main criteria, with Social representing 52.56%, Technical 27.28%, Economic 12.42% and Environmental 7.73%.

Table 11. Pairwise comparison of criteria and their weights

	Technical	**Environmental**	**Economic**	**Social**	**Weights**
Technical	1	4	3	1/5	**27.28%**
Environmental	1/4	1	1/2	1/9	**7.73%**
Economic	1/3	2	1	1/7	**12.42%**
Social	3	5	4	1	**52.56%%**

An excel sheet was developed following step by step of the AHP method as described previously using equations (1), (2) and (3) respectively to calculate weights of criteria, checking the consistency of the matrix of decision. the AHP method evaluates the different weights of the criteria depending on the preferences of the experts consulted to obtain the following results shown graphically in the figure 14:

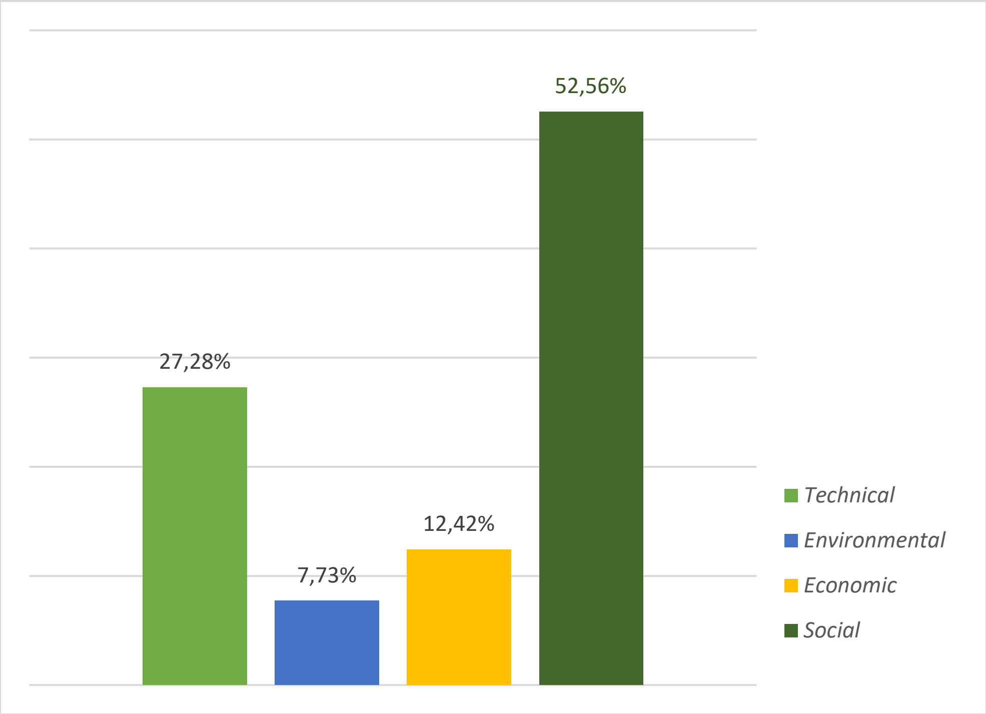

Figure 14. Weights of the four criteria

Consistency Checking

As recommended in the literature by many authors, a consistency checking is vital before continuing with further calculation (Daim, Oliver, & Kim, 2013; Wan, Yan, Zhang, Shi, & Fu, 2014; Algarín, Llanos, & Castro, 2017).

The consistency ratio, in this case, was evaluated at $0.04 < 0.1$. Therefore, matrix of criteria is consistent.

4.2. WEIGHTS OF THE SUB-CRITERIA

In this section, for the four criteria, we evaluate the weights of all the sub-criteria in the decision-making method using AHP method again as recommended in the methodology framework.

4.2.1. Weights of Technical Sub-criteria

The selected technical sub-criteria and their importance in the experts' preferences are reported in the table 12. Using again the equations (1), (2) and (3) of the AHP method in an Excel sheet, the weights of the figure 15 were obtained.

Table 12. Pairwise comparison of Technical sub-criteria

	Energy availability	**Efficiency**	**Energy System Safety**	**Technology Maturity**
Energy availability	1	3	4	5
Efficiency	1/3	1	2	3
Energy System Safety	1/4	1/2	1	1/2
Technology Maturity	1/5	1/3	2	1

The Consistency Ratio is 0.06 <0.1 and the weights of the Technical Sub-criteria are:

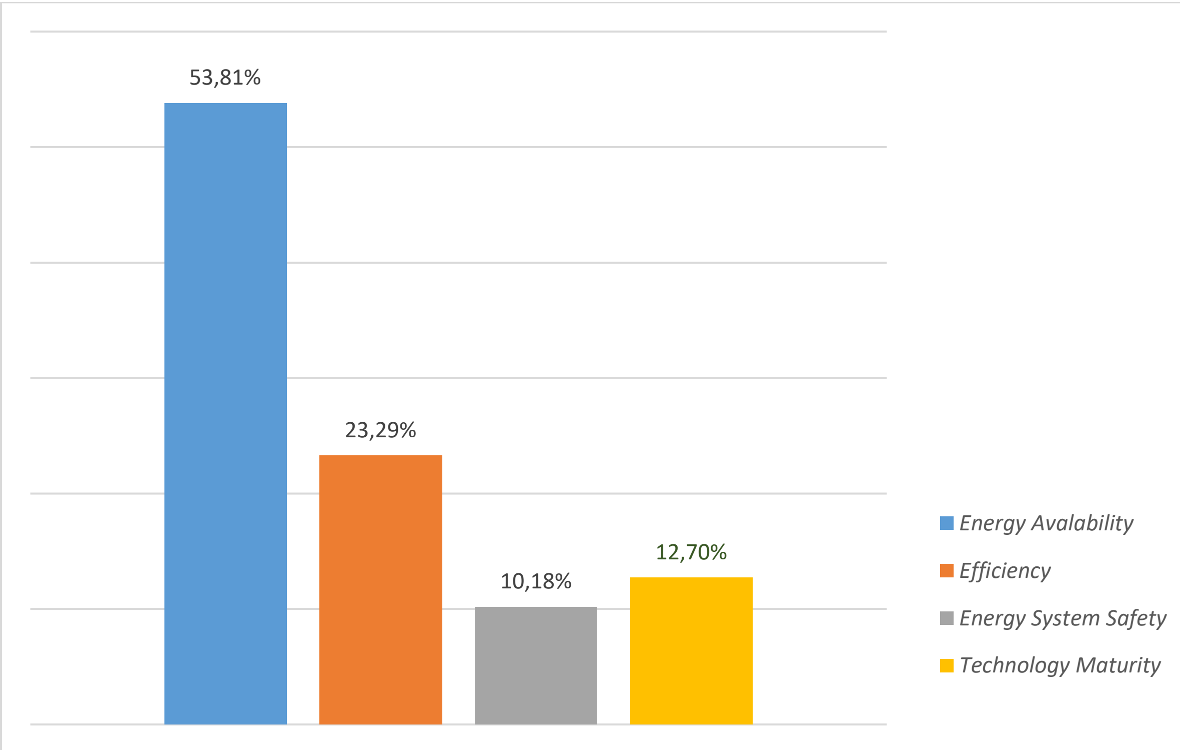

Figure 15. Weights of the Technical Sub-criteria

4.2.2. Environmental Sub-criteria weights

The selected sub-criteria and their importance as the expert's preferences are given in table 13 below.

Table 13. Pairwise comparison of Environmental sub-criteria

	CO_2 Emissions	**SO_x Emissions**	**NO_x Emissions**	**Land Requirement**	**Impact on ecosystem**
CO2 Emissions	1	2	2	0,333	3

SO x Emissions	0,5	1	1	0,25	1
NO x Emissions	0,5	0,5	1	0,25	1
Land Requirement	3	4	4	1	2
Impact on ecosystem	0,333	1	1	0,5	1

The Consistency Ratio is 0.01 <0.1 and the weights of the Environmental Sub-criteria are:

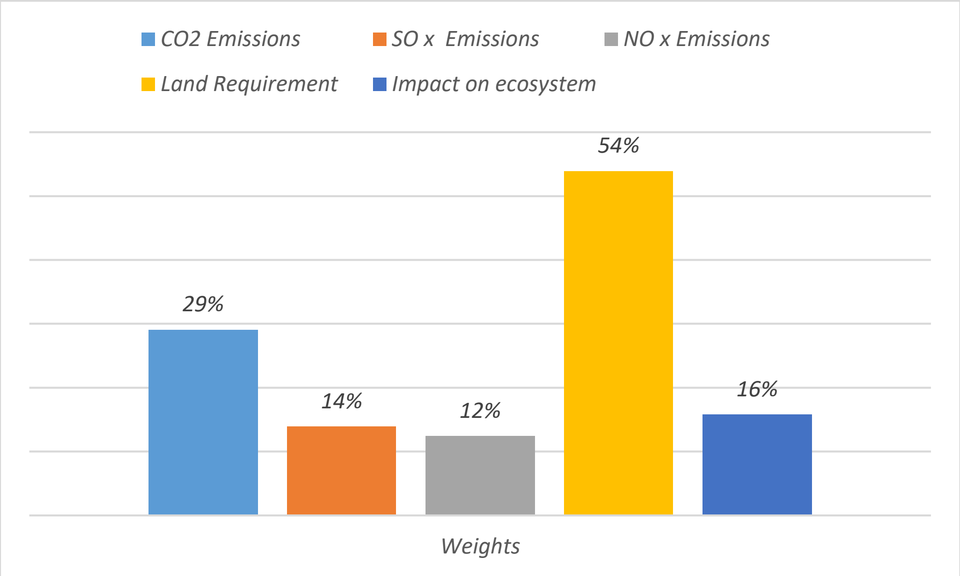

Figure 16. Environmental Sub-criteria weights

4.2.3. Economic Sub-criteria weights

The selected Economic sub-criteria and their importance in the preferences are:

Table 14. Pairwise Comparison of Economic Sub-criteria

	Capital Cost	O&M Cost	Economic Development	Externality Cost	Levelized Cost of Electricity
Capital Cost	1	3	4	2	2
O&M Cost	0,333	1	1	0,333	1
Economic Development	0,25	1	1	2	1
Externality Cost	0,5	3	0,5	1	1
Levelized Cost of Electricity	0,5	1	1	1	1

The Consistency Ratio is 0.01 <0.1 and the weights of the Economic Sub-criteria weights are:

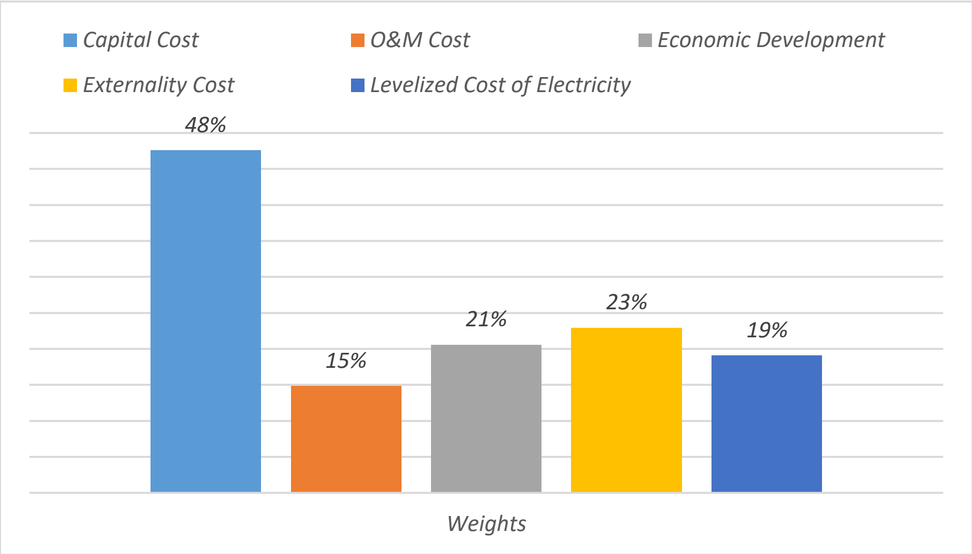

Figure 17. Weights of Economic Sub-criteria

4.2.4. Social Sub-criteria Weights

The selected Social sub-criteria and their importance in the preferences are:

Table 15. Pairwise Comparison of Social Sub-Criteria

	Job Creation	Social acceptance	Impact on Health
Job Creation	1	2	3
Social acceptance	0,5	1	4
Impact on Health	0,333	0,25	1

The Consistency Ratio is 0.01 <0.1 and the weights of the Social Sub-criteria weights are:

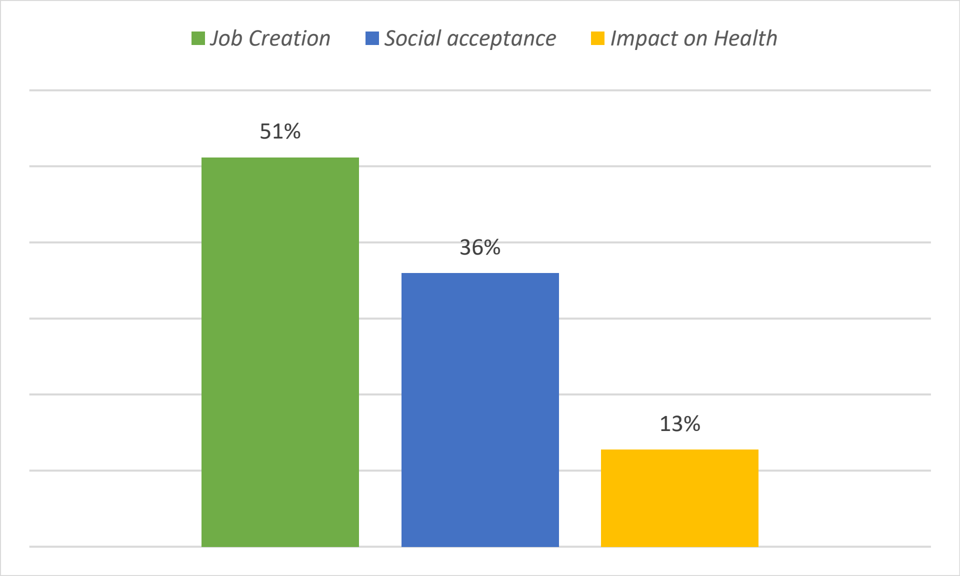

Figure 18. Social Sub-criteria weights

A compilation of all sub-criteria weights it is given below:

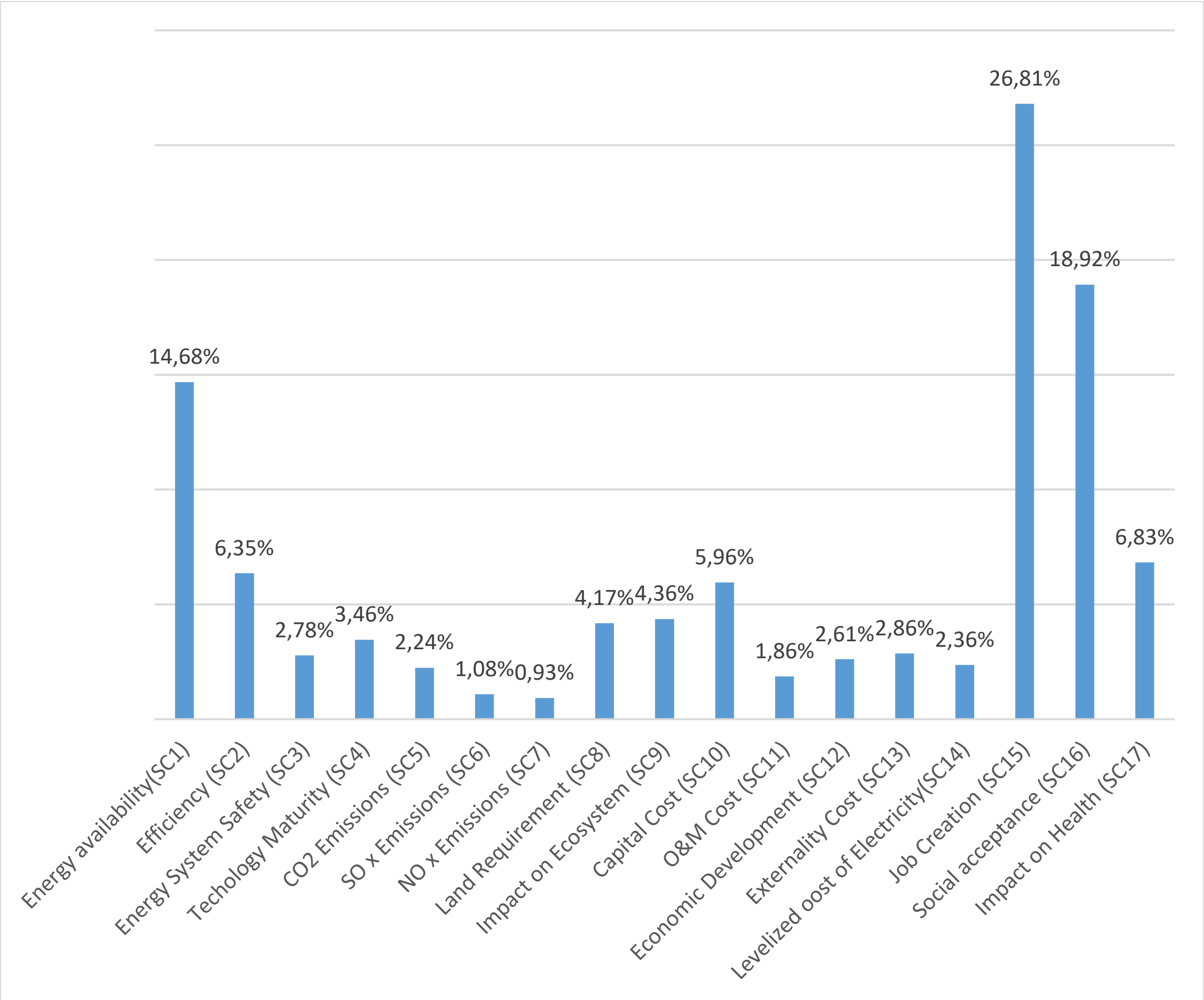

Figure 19. Sub-criteria weights

4. 3. EVALUATION OF ALTERNATIVES BY TOPSIS METHOD

The seven alternatives of energy resources of Idjwi Island established in the figure 13 above and the 17 criteria with their respective weights give the matrix decision see the table 16 below for TOPSIS analysis according to the equation (4).

The matrix of the decision was taken in an Excel sheet, the first step of the TOPSIS method was to normalize the decision matrix using the equation (5) in order to obtain a dimensionless normalized decision matrix (Table 17).

In the same Excel sheet, the equation (6) was used considering the weight of each criterion to obtain the weighted normalized matrix given by the table 18 below.

Table 16. Matrix of Decision making for TOPSIS Analysis

	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17
Weights	14.6%	6.3%	2.7%	3.4%	2.2%	1%	0.9%	4.1%	4.3%	5.9%	1.8%	2.6%	2.8%	2.3%	26.8%	18.9%	6.8%
Solar PV	5.4	15%	0.95	0.4	46	0.12	0.15	150	0	3875	39.55	2.5%	70.1	126	0.87	1.7	2
Small Hydro	6.2	90%	0.98	0.75	4	0.08	0.009	57	0	4525	52.32	3%	65	245	0.8	1.5	2
Biomass	7.08	25%	0.85	0.6	18	0.03	1.3	200	0.1	8312	46.4	3%	42	80	0.5	1.5	1.4
Wind	1.2	35%	0.85	0.6	10	0.12	0.04	200	0	2213	24.6	5%	28.5	156	0.17	1.2	1.1
Geothermal	0.2	16%	0.9	0.8	18	0.03	1.3	200	0.1	8312	46.4	3%	33	55	0.21	1	1.8
Diesel	10.2	80%	0.9	0.9	778	7	1.2	28	149	5530	93.28	9%	99.1	90	0.35	0.1	0.5
Natural Gas	59.5	88%	0.7	0.92	469	0.1	0.6	34	123	1023	31.7	6%	57.3	43	0.62	1.2	0.8

Table 17. Dimensionless normalized decision matrix

	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17
Solar PV	0.001434836	0.06103764	0.17534469	0.10698334	5.55472E-05	0.002039044	0.02635009	0.001015648	0	1.84353E-05	0.002092129	1.42653352	0.00270569	0.001053415	0.39069517	0.15070922	0.13071895
Small Hydro	0.001647404	0.36622584	0.18088189	0.20059376	4.83019E-06	0.001631235	0.00158101	0.000385946	0	2.15277E-05	0.002767641	1.71184023	0.002508843	0.002048307	0.35925992	0.13297872	0.13071895
Biomass	0.001881229	0.1017294	0.15688735	0.16047501	2.17358E-05	0.000611713	0.22836741	0.001354197	2.6788E-06	3.95443E-05	0.002454483	1.71184023	0.001621098	0.000668835	0.22453745	0.13297872	0.09150327

Wind	0.000318852	0.14242116	0.15688735	0.16047501	1.20755E-05	0.002446852	0.12296707	0.001354197	0	1.05283E-05	0.001301299	2.85306705	0.001100031	0.001304228	0.07634273	0.10638298	0.07189542
Geothermal	5.31421E-05	0.06510682	0.16611602	0.21396667	2.17358E-05	0.000611713	0.22836741	0.001354197	2.6788E-06	3.95443E-05	0.002454483	1.71184023	0.00127372	0.000459824	0.09430573	0.08865248	0.11764706
Diesel	0.002710246	0.32553408	0.16611602	0.24071251	0.000939472	0.142733052	0.21080069	0.000189588	0.00399143	2.63089E-05	0.004934357	5.13552068	0.00382502	0.000752439	0.15717622	0.00886525	0.03267974
Natural Gas	0.015809767	0.35808749	0.12920135	0.24606168	0.00056634	0.002039044	0.10540034	0.000230213	0.00329494	4.86692E-06	0.001664711	3.42368046	0.002211641	0.000359499	0.27842644	0.10638298	0.05228758

Table 18. Weighted normalized matrix

	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17
Solar PV	0.000200877	0.00384537	0.04734307	0.00363743	1.22204E-06	2.03904E-05	0.00023715	4.16416E-05	0	1.08768E-06	3.76583E-05	0.03708987	7.57593E-05	2.42285E-05	0.10158074	0.02712766	0.08888889
Small Hydro	0.000230637	0.02307223	0.04883811	0.00682019	1.06264E-07	1.63123E-05	1.4229E-05	1.58238E-05	0	1.27013E-06	4.98175E-05	0.04450785	7.02476E-05	4.71111E-05	0.09340758	0.02393617	0.08888889
Biomass	0.000263372	0.00640895	0.04235959	0.00545615	4.78189E-07	6.11713E-06	0.00205531	5.55221E-05	1.1519E-07	2.33311E-06	4.41807E-05	0.04450785	4.53908E-05	1.53832E-05	0.05837974	0.02393617	0.06222222
Wind	4.46393E-05	0.00897253	0.04235959	0.00545615	2.6566E-07	2.44685E-05	0.0011067	5.55221E-05	0	6.21172E-07	2.34234E-05	0.07417974	3.08009E-05	2.99972E-05	0.01984911	0.01914894	0.04888889
Geothermal	7.43989E-06	0.00410173	0.04485133	0.00727487	4.78189E-07	6.11713E-06	0.00205531	5.55221E-05	1.1519E-07	2.33311E-06	4.41807E-05	0.04450785	3.56642E-05	1.0576E-05	0.02451949	0.01595745	0.08
Diesel	0.000379434	0.02050865	0.04485133	0.00818423	2.06684E-05	0.001427331	0.00189721	7.77309E-06	0.00017163	1.55223E-06	8.88184E-05	0.13352354	0.00107101	1.73061E-05	0.04086582	0.00159574	0.02222222
Natural Gas	0.002213367	0.02255951	0.03488436	0.0083661	1.24595E-05	2.03904E-05	0.0009486	9.43875E-06	0.00014168	2.87148E-07	2.99648E-05	0.08901569	6.1926E-05	8.26847E-06	0.07239087	0.01914894	0.03555556

The Positive Ideal Solution and Negative Ideal Solution were determined by the equations (7) and (8) respectively:

A^+= {0.002213367; 0.023072228; 0.048838111; 0.008366097; 1.06264E-07; 6.11713E-06; 1.4229E-05; 7.77309E-06; 0; 2.87148E-07; 2.34234E-05; 0.133523538; 3.08009E-05; 8,26847E-06; 0.101580744; 0.02712766; 0.088888889}

A^-= {7.43989E-06; 0.003845371; 0.034884365; 0.003637433; 2.06684E-05; 0.001427331; 0.002055307; 5.55221E-05; 0.000171631; 2.33311E-06; 8.88184E-05; 0.037089872; 0.000107101; 4.71111E-05; 0.019849111; 0.001595745; 0.022222222}

The separation measures (so called Euclidian distances) from Ideal solution (Si+) and to negative solution (Si-) were calculated using the equations (9) and (10). The closeness to ideal solution was evaluated using equation (11) and the summary of rank from the TOPSIS method is given in the table 19 below.

Table 19. Ranking of different alternative energies from TOPSIS calculation

	Si+	Si-	Ci	**Rank**
Solar PV	0.098	0.109	0.5259	**2**
Small Hydro	0.089	0.1048	0.5395	**1**
Biomass	0.104	0.06088	0.3689	**5**
Wind	0.11	0.04983	0.3115	**7**
Geothermal	0.122	0.06112	0.33706	**6**
Diesel	0.9388	0.10069	0.5174	**3**
Natural Gas	0.077	0.07705	0.5078	**4**

4.4. DISCUSSION OF RESULTS

The energy planning was done on the surveys' results from the local community, experts in energy field, local authorities, NGO of the region. Out of these surveys, social criteria were highly weighted compare to other criteria such as technical, economic and environment. The respondents consulted showed the importance of job creation for rural community by an electrification project and the acceptance of the community of any project as their priority. Another aspect was the land requirement for the project, and the survey shows that land is essential for the villagers, thus a good source of energy which requires less land for implementation was the most welcome.

The MCDM hybrid method AHP and TOPSIS were used to evaluate the suitable energy resource to power Idjwi Island in this thesis.

The seven energy alternatives (Solar PV, Small Hydro Power Plant, Biomass, Geothermal, Diesel and Natural Gas) were compared through a TOPSIS method, concerning each of the 17 established criteria grouped in 4 main criteria (technical, economic, social, environmental).

The weights obtained by the AHP method according to the experts' choices and preferences. Table 16 summarizes the matrix of alternatives, weights of criteria and their respective affected values for TOPSIS analysis of the problem. The two first places of relevance were for Small Hydro mini-grid and Solar PV energy. This result shows how renewable energies can meet the energy needs of Idjwi Island and improve the social life of the community.

The third and fourth preference was alternated between Diesel and Natural Gas as illustrated in the table 19. From this result, we can confirm that for the case of Idjwi, Diesel Generator can be used as back up in combination with Hydro or Solar PV in order to meet the peak demand of the island.

The natural gas in the Kivu lake seems to be an alternative that can be exploited and remaining in the preferences of the local community.

Energy projects accompanied by sophisticated technologies and promise affordable electricity even tend to fail many times, due to ignorance or less importance of social factors. For that, the methodology used in this study can assist decision-makers in the policy sector, investors, and energy's project developers of the country to properly plan for future energy project for rural electrification.

5. CONCLUSION AND RECOMMENDATION

Based on the available energy resources of the Idjwi island in the Democratic Republic of Congo, this thesis work has been devoted to select the best source of energy to electrify the Idjwi Island. A step by step methodological framework for selecting energy alternative was formulated in this work using two Multi-Criteria Decision-Making methods.

To meet the objectives of this thesis, the Analysis Hierarchy Process (AHP) was used to weight all the 17 criteria maintained for the analysis of the problems. According to the preferences of the community and the experts, the social criteria such as Job creation and social acceptance were highly weighted respectively 26.8% and 19.8%. All weights of criteria obtained were used on the Technique of Order Preferences by Similarity to Ideal Solution (TOPSIS) to rank the seven alternatives of available energy resources on the Idjwi island (Solar PV, Small hydro, Biomass, Geothermal, Wind, Diesel and Natural Gas). One scenario was developed which consist of the fact that Social aspects of the project were the priority followed by technical, economic and environmental aspects meet sustainability of any energy project at Idjwi.

Throughout of this research, the small hydropower plant system and solar photovoltaic were ranked the two first alternatives in which investment could meet the need and the preferences of the local community of Idjwi. The small hydro has a closeness parameter to an ideal solution of 0.5395 and solar PV of 0.5259. They were followed by the Diesel and Methane Gas projects as third and fourth preferences to power the Island, the biomass, Geothermal and wind were the last on the list according to the scenario developed. These results clarify which type of hybrid system can be developed on the Island to power the Island. The results proved that the Democratic Republic of Congo which has huge amount of energy resources is facing a situation of energy poverty in the rural areas and a good energy planning involving the local community can reinforce the ownership of the project by the community and assure its sustainability.

Energy projects accompanied by sophisticated technologies and promise affordable electricity even tend to fail many times, due to ignorance or less importance of social factors. For that, the methodology used in this study can assist decision-makers in the policy sector, investors, and energy’s project developers of the country to properly plan for future energy project for rural electrification.

Further research can be oriented on the sizing of the energy mini-grid systems based on the results of this project to meet the energy needs of the local community. This mini-grid can be either hybrid systems such as Small Hydropower system combined to Solar Photovoltaic with a back-up of Diesel Generator for peak loads. A comparison of more than one scenario can reinforce the reliability of the methodological framework. In this regard, further research should consider multiple scenarios.

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7. APPENDIX

7.1. Appendix 1

QUESTIONNAIRE D'ENQUETE POUR LA COMMUNAUTE

Sujet : Quel mix énergétique pour un projet de l'électrification rurale de l'île d'Idjwi ?

Partie I. Connaissance générale sur la personne interviewée :

Question 1. Quel est ton nom ? Quel est votre genre (Masculin ou Féminin ?)

R /

Question 2. Quel âge a tu ?

R / a) 18 à 25 b) 25 à 35 c) 35 à 45 d) 45 à 65 e) 65 à 85

Question 3. Quel est ton activité pour vivre ?

R/ a) Commerçant b) Fonctionnaire de l'Etat c) Enseignant d) Cultivateur e) Eleveur f) Homme ou Femme au foyer

Question 4. Combien de personnes vivent dans votre famille ?

R /

Question 5. Quel est ton niveau de scolarisation ?

R/ a) Aucune b) Ecole Primaire c) Secondaire d) Universitaire premier cycle e) Universitaire Deuxième Cycle f) Autres à préciser

Partie II. Intérêt porté à un projet d'électrification rurale d'Idjwi

Question 1. Sur un échelle de 1 à 10, combien donnera tu pour montrer l'importance d'un projet d'électrification de l'île d'Idjwi

R/

Question 2. Quelles sont les activités dont tu fais tout le jour et qui demande de l'énergie électrique

R/

Question 3. Payez-vous de l'argent pour couvrir ces besoins en électrification ?

R/ a) Oui b) Non

Question 4. Si Oui ! Combien payez-vous pour couvrir vos besoins ?

R/

Question 5. Si un projet d'électrification rurale doit être développé pour l'île d'Idjwi, il doit être de nature :

R/ a) Solaire b) Hydroélectrique c) Biomasse d) Groupe Diesel e) Gaz Méthane f) Combinaison de deux ou trois à préciser

Question 6. Combien gagnez-vous par jour comme revenus ?

R) a) 1 à 2 $ b) 2 à 5 $ c) 5 à 10 d) 10 à 20 e) 20 à 30

Question 7. Quels sont les équipements électriques dont vous disposer dans votre maison ? Ecole ? Hôpital ?

R/

Question 8. Quels sont les équipements électriques que vous pouvez acheter si vous aviez de l'électricité ?

R/

Question 9. A quelle heure de la journée utilisez-vous vos équipements électriques ?

R/

Question 10. Avez-vous une source de l'électricité chez vous ? Dans votre établissement ? Si oui le quel ?

R/

Question 11. Combien pouvez-vous payé par mois pour l'électricité si une fois vous l'avez ?

R/

7.2. Appendix 2

QUESTIONNAIRE D'ENQUETE POUR LES EXPERTS EN ENERGIE

Sujet : Quels critères devrions nous considérés pour sélectionner une source énergétique à Idjwi?

Partie I. Connaissance générale sur la personne interviewée :

Question 1. Quel est ton nom ? Quel est votre genre (Masculin ou Féminin ?)

R /

Question 2. Quel âge a tu ?

R / a) 18 à 25 b) 25 à 35 c) 35 à 45 d) 45 à 65 e) 65 à 85

Question 3. Quelle est votre profession?

R/ a) Professeur d'Université b) Electricien c) Ingénieur Civil d) Autorité Administrative e) Assistant à l'université f) Chef de Travaux

Partie II. Priorité entre les critères selon votre avis ?

Question 4. Entre les 4 critères, lequel est plus prioritaire pour la population d'Idjwi en matière d'électrification de l'Ile d'idjwi ?

R /

1) Economique
2) Environnemental

3) Social
4) Technique

Question 5. Sur une échelle de 1 à 10, veuillez hiérarchiser ces différents critères ?

R/

1) Economique
2) Environnemental
3) Social
4) Technique

Question 6. A votre avis, sur la liste ci-dessous de critères techniques considérés dans la littérature. Lister 5 critères importants pour Idjwi

R/ 1) Efficacité 5) Sécurité du système

2) Fiabilité 6) Durée de vie du projet

3) Disponibilité de la resources 7) Stabilité du système

4) Maturité 8) couvrir la demande

Question 7. Sur une échelle de 1 à 10, veuillez hiérarchiser les cinq critères sélectionnés à la question numéro 6

R/

Question 8 . A votre avis, sur la liste ci-dessous de critères économiques considérés dans la littérature. Lister 5 critères importants pour Idjwi

R/ 1) Capital d'Investissement 5) Prix de l'énergie

2) Coût d'Opération et Maintenance 6) Les externalités

3) Temps de retour sur Investissement 7) Développement économique

4) Valueur nette actualisée 8) Le cycle de vie des coûts

Question 9. Sur une échelle de 1 à 10, veuillez hiérarchiser les cinq critères économiques dont vous avez sélectionnés à la question numéro 8

R/

Question 10. A votre avis, sur la liste ci-dessous de critères environnementaux considérés dans la littérature. Lister 5 critères importants pour Idjwi

R/ 1) Emission de CO_2

2) Utilisation de la terre

3) Impact sur l'écosystème

4) Emissions NO_x

5) Emissions de SO_x

6) Les bruits

7) Emission de particules

Question 11. Sur une échelle de 1 à 10, veuillez hiérarchiser les cinq critères économiques dont vous avez sélectionnés à la question numéro 10

R/

Question 12. A votre avis, sur la liste ci-dessous de critères sociaux considérés dans la littérature. Lister 5 critères importants pour Idjwi

R/ 1) Création d'emploi

2) Accepté par la communauté

3) Bénéfice social

4) Impact visuel

5) Développement local

6) Impact sur la santé

7) Revenus sur les emplois créés

Question 13. Sur une échelle de 1 à 10, veuillez hiérarchiser les cinq critères sociaux dont vous avez sélectionnés à la question numéro 12

R/

Question 14. Avez-vous un commentaire à ajouter ?

Annex 1. RESEACH GRANT USE

FINANCIAL REPORT FOR THE RESEARCH GRANTS				
N°	**Designation**	**Unitary Price (USD)**	**Number**	**Total Price (USD)**
1	Internet Data (Package of 30GB)	40	5	200
2	Ticket (Goma to Idjwi)	25	2	150
3	Go Pass taxis	10	1	10
4	Workshop Organization with Local Comunity	150	1	150
5	Research Assisant fees	100	2	200
6	Questionnaire Printing, Pens	0,3	150	50
7	Transport on the Island	50		50
8	Commission of ASAIDI NGO	150		150
	SUB-TOTAL			**960**
	Flight Ticket (PAUWES)			1106
	TOTAL			**2066**