T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

ECONOMIC DISPATCH FOR POWER SYSTEMS IN IMPROVING THE ENERGY NEEDS OF SOMALIA USING MULTI CRITERIA DECISION MAKING TECHNIQUES (VIKOR, TOPSIS, WSM AND AHP)

THESIS

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DECLARATION

I hereby declare with respect that the study “Economic Dispatch for Improving the Energy needs of Somalia Using a Multicriteria Decision Making Technique”, which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the Project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the References section.

Ahmed Osman Omar Jelle

FOREWORD

I would like to express my gratitude to the people who, in a way or another, contributed to the completion of this work.

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Finally, I am thankful to all those who contributed to make this work a success.

August, 2020 **Ahmed Osman Omar Jelle**

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ABBREVIATIONS

ADRA:	Adventist Development and Relief Agency
AfDB:	African Development Bank
A/I:	Action/investment
ENEE:	Ente Nazionale Energia Elettrica
ESAIP:	Energy sector action/investment programme
EU:	European Union
FGS:	Federal Government of Somalia
HFO:	Heavy fuel oil
IGAD:	Intergovernmental Authority on Development
IJA:	Interim Juba Administration
IMF:	International Monetary Fund
ISWA:	Interim South West Administration
LPG:	Liquid petroleum gas
MEWR:	The Federal Government of Somalia's Ministry of Energy and Water Resources
NEC:	Nugaal Electricity Company
NGO:	Non-governmental organisation
PPP:	Public-private partnership
PSAWEN:	Puntland State Authority for Water, Energy and Natural Resources
SDG:	Sustainable Development Goal
SE4All:	Sustainable Energy for All
SEA:	Somaliland Electricity Agency
TA:	Technical assistance
UN:	United Nations
UNDP:	United Nations Development Programme
US:	United States
USAID:	United States Agency for International Development
WB:	World Bank

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ECONOMIC DISPATCH FOR POWER SYSTEMS IN IMPROVING THE ENERGY NEEDS OF SOMALIA USING MULTI CRITERIA DECISION MAKING TECHNIQUES (VIKOR, TOPSIS, WSM AND AHP)

ABSTRACT

Somalia has been in turmoil since the fall of the central government at the end of the 20^{th} century, but since recent times there have some promising change taking place in the country. During the looting and the chaos much of Somali's infrastructure has been destroyed. Electrical grid lines operated by the government which was the heart of power distribution has been either destroyed or looted for parts. The Energy sector of Somalia has long been neglected and it is dominated by private companies. In the last decade more and more outside investment particularly governments have been coming into the country. The European Union and the World Bank have proposed several different projects for improving the electrical generation and distribution of the Somalia. They hope that if these projects or ones like them are implemented, they could bring significant improvements to the energy sector.

In this thesis, using multi criteria decision making (MCDM) methods, the projects are evaluated through several different criterions mainly the costs of these projects. MCDM methods like VIKOR, TOPSIS, WSM and AHP are used in this thesis to find the best method to use for such daunting tasks. Multi criteria decision making methods have time and again being proven to be helpful to sort out different alternatives and give clear decision. But when the problem gets complex and the decision makers are getting more and more MCDM methods have some shortcoming to provide a clear answer. In this thesis a new and easy system is presented to improve these shortcomings in the multi criteria decision making techniques giving them clear and unbiased data. With the help of this new system complex data can be broken down into easy ones that the MCDM methods could easily navigate through and present strong argument.

Keywords: *MCDM, VIKOR, TOPSIS, WSM, AHP, Per Unit Systems, Sensitivity Analysis, Weight Calculation, Standard Deviation Method.*

EKONOMIK DAĞITIMA GÖRE ÇOKLU KRITERLI KARAR VERME TEKNIKLERI (VIKOR, TOPSIS, WSM VE AHP) KULLANARAK, SOMALI'NIN GÜÇ SISTEMLERININ İHTIYAÇLARININ İYILEŞTIRILME

ÖZET

Somali, 20. yüzyılın sonlarında ortaya çıkan hükümet sorunundan bu yana kargaşa içindedir, bununla beraber son zamanlarda ülkede umut verici bir değişiklik yaşanmaktadır. Söz konusu bu kargaşıklık sırasında söz konusu olan yağma ve kaos sırasında Somali'nin altyapısının çoğu yok edilmiştir. Güç dağıtımının kalbi olan hükümet tarafından işletilen elektrik şebekesi hatları parçalara ayrıldı ya da yağmalanmıştır. Uzun zamandır ihmal edilen Somali'nin Enerji sektörü halen özel şirketler tarafından yönetilmektedir. Son on yılda özellikle yabancı devler ülkeye giderek daha fazla yatırım yapmaktadır. Avrupa Birliği ve Dünya Bankası, Somali'nin elektrik üretimini ve dağıtımını iyileştirmek için birkaç farklı proje önermiştir. Önerilen bu projeler veya benzeri projeler uygulanırsa, enerji sektörüne önemli gelişmeleri sağlayabileceklerini umuyorlar.

Bu tezde, çoklu kriterli karar verme yöntemleri kullanılarak, projelerin esas olarak maliyetleri üzere birçok farklı kriter ile değerlendirilmesi yapılmıştır. VIKOR, TOPSIS, WSM ve AHP gibi Çoklu Kriterli Karar Verme yöntemleri; zorlayıcı görevlerde kullanılacak ve en iyi yöntemi bulmak için kullanılmıştır. Çoklu kriterli karar verme yöntemlerinin, farklı alternatifleri sıralamak ve açık bir karar vermek için yararlı olduğu defalarca kanıtlanmıştır. Ancak sorun karmaşıklaştığında ve karar vericiler gittikçe arttığında, çoklu kriterli karar verme yöntemlerinin net bir cevap vermek için bazı eksiklikleri vardır. Bu tezde, çok kriterli karar verme tekniklerinde bu eksiklikleri gidermek için ve açık ve tarafsız veriler sağlayan yeni ve kolay bir sistem sunulmuştur. Bu yeni sistemin yardımıyla karmaşık veriler, MCDM yöntemlerinin kolayca ulaşabileceği ve güçlü bir argüman sunabileceği sonuçlar elde edilmiştir.

Anahtar kelimeler: *Çoklu kriterli karar verme yöntemleri, VIKOR, TOPSIS, WSM, AHP, Birim Sistemleri, Duyarlılık analizi, Ağırlık Hesaplama, Standart Sapma Yöntemi.*

1. INTRODUCTION

1.1 History of Somalia

Before Somalia gained its independence, the country was divided into parts. Northern Somalia was occupied by Britain for 1920-1950 and the southern part was controlled by Italy. By the late 30s and the beginning of 1940s Somali people started to advocate and fight for its independence from these two foreign powers. After the end of world war II with the establishment of the United Nations (UN) there was glimmer of hope of independence for Somalia and many other African countries. In 1950s Somalia was one of the attendees at a UN summit for the colonized African countries and the discussion of their independence was in the topic. The UN and the Somali delegates agreed that the country would enter a ten-year period for the preparation and establishment of a fully independent Somali nation. The plan was that Italy would have presence in both regions of the country and that they would help the young Somali leaders into the formation of their country, but the British would leave the country. Fast forward to 1960 Somalia and many other countries would gain their independence from their oppressors and the northern and the southern regions came together to form what is now known as Somalia. By the end of 1980s there were massive uprising against the ruling government which was formed entirely of the military officials who gained control after a coup d'état in 1969. The country entered a two-decade long period of turmoil and violence, and tribalism was the main source of these disruptions and many Somalis lost their lives and their livelihood. The northern region declared independence from the rest of Somalia and are to this day seeking international recognition for their succession, every other region formed its own brand of government and started to act as self-governing elements. But after the election of 2017, which resulted in the election of the most popular president since Mohamed Siad Barre, who was overthrown in 1991, hope and optimism towards the future entered the hearts and minds of the Somali people. Many Somali diasporas who fled the country after the overthrow of the central government started to gradually come home with their families. Foreign interest in Somalia became more evident when the Turkish government started to heavily invest in improving the health sector by taking over old hospitals and rebuilding them and they also are helping the government with the restructure of the damaged Somali infrastructure like the roads of the main cities. The main airport of Mogadishu was taken over by a Turkish company and together with their expertise and investment built a new and modernized terminal. Also, the seaport of Mogadishu is also controlled by another private Turkish company and the have done some work into the repairment of the port docs and warehouses. The Turks are only one example of the foreign actors showing interest in investing the long-term development of the country and the government is encouraging more and more outside investments, private of governments. In 2018, in the northern region the Berbera city's seaport was given control to a private company from the United Arab Emirates with the promise of job creation and investment into the development of the city and rebuild the seaport.

1.2 Brief information about the current state of the Energy Sector

After the overthrow of the military rule that last for 29 years (1969-1991) violence ensued throughout the country, looting and destruction of public property resulted in a nation-wide infrastructure damage. One of the well-damaged setups was the energy sources. Before the uprising started in the 1980s electricity was provided solely by the government. By the end of 1980, Somalia's generation capacity was over 200MW which 150MW of this was Mogadishu. The major cities like the capital Mogadishu, Hargeisa and Kismayo had conventional grid capacity since most of the country population and economy was concentrated on these cities, other small cities had in some way their own grid connections which served their residents but the quality of these grids mainly depended on the quality of service and the availability of fuel and no cities had grid interconnection. According to an estimate done in 2008 Somalia's power production was about 326GWh or just under 33kWh/capita/year. Power generation is completely based diesel-fueled and the suppliers of the electricity are mainly standalone electricity suppliers who operate on local low-voltage mini grids. State supplied electricity has entirely stopped after 1990 when the government was overthrown, the years after that electricity became extremely expensive. Small private companies emerged to fill the gap left by the government. They scattered throughout the nation sometimes even within the same city one could find more than 20 of those providing power to their customers. They all had one thing in common and that is the use of traditional diesel generators which generated low voltage electricity only enough for handful of customers. As the years went by these companies started to widen their territories by bringing in more sophisticated generators so that they could provide more customers. After the 2010, in Mogadishu alone 90% of the electricity providers came together under one umbrella to form the company BEKO who is responsible for the generation and distribution of electricity in the capital. The companies got bigger, but one thing still hasn't changed very much and that is the quality of the electricity. It is still the low voltage power people used to have only now its 24 hours. It is this way because the private companies didn't invest more into the electrical grid systems which was damaged heavily in 1991 and the years after that. Such as loss caused great technical/ non-technical or financial losses between generation of the electricity and its distribution. But not all electricity in Somalia is generated by private companies, there are also some publicly supplied electricity in the central and the northern regions of the country.

Energy Sector Organization and Policies

Mogadishu and southern Somalia

The Ministry of Energy and Water Resources under the direction of the Somali government enjoys and exercises the authority to control oversee the energy industry in the capital city Mogadishu. Though it is the sole government authority, it still faces many obstacles that prevent the ministry from doing its duty and those are inadequate staff and limited budgets. But after the regime came into power word was that there will be more focus given to this ministry and the provide them with the much-needed budget and staff. Over the years, the ministry has time and again emphasized on their need for government support by training qualified workers and widen their capacity for technical assistance, but every time those demanded fell on deaf ears. There is no legislation overseeing electricity, nor is there any governing body overseeing the regulatory framework. The ministry has some ambitious plans of its own. One of those plans to improve the generational capability of the power systems in Somalia is taking advantage on the renewable energy sources, which is clean and frankly cheap alternative power sources, since Somalia has a great potential for renewable energy sources. Other issue that the ministry voiced it support of it to put in place legislations and regulation for the energy sector which could result in a more competitive market that is good for the country's economy in terms of job creation and relieve the public of the high prices they pay for electricity. It is important to note that the energy market is heavily dominated by big corporations that don't provide the public with much of a choice because of the monopoly they enjoy. So, there first step in regulating this sector would be the breakup of these big private companies and after that encourage them with investing more into grid interconnections, since most of the generated electricity is lost during transmission because of the use of low voltage wirings.

Puntland and Central Somalia

The situation in the state of Puntland is entirely separate from what is going on in Mogadishu and the Southern part of Somalia. With the help of the regional government the Ministry of Energy managed to bring new provision under the public-owned power company the National Electric Energy Entity or Ente Nazionale Energie Elettrica or its short version (ENEE). Although it has shrunk significantly over the past two decades its state-owned power plants survived the chaos during those periods. They plan to invest more money into reviving this once great company and provide the citizens there with government supplied electricity. Although, the private companies there are not as big as the ones in other regions, it seems that they have an agreement between them to keep things as they are. This plan has faced many oppositions mainly from the private sector who are lobbying the politicians to limit the government's power in the energy sector. Because of the wide corruption in the government these private investors have time and again managed to kill legislations intended to limit their market monopoly. Though the regional government of Puntland does not have a ministry overseeing the energy sector, it solely relies on the Puntland State Authority for Water, Energy and Natural Resources or better known as

PSAWEN, and this administration gets its orders directly from the office of the regional president but it is short of qualified personnel and it does not have the required expertise to oversee such a competitive industry. As the case we mentioned above the Puntland state-government does not have a written rules and regulations to maintain fair market and competition in the energy sector. The Ministry of Energy's office in Puntland comprises of a few employees mainly the appointed chairman of the ministry and together with a handful of staff who are not trained for such an office.

Somaliland and Northern Somalia

The northern region of Somaliland which declared their own independence for the rest of Somalia have their own way of doing things. Their government institutions work somewhat more efficiently than the recognized Somali government and situation there is completely different from the rest of the country. In Somaliland their own established Ministry of Energy and Mineral Resources exercises the sole authority for policies and regulations also the control of the energy sector. As it reported the government there did some restructuring among their department and the result was the breakup of the ministry by transferring the water resources to another ministry. The electricity agency Somaliland Electricity Agency (SEA), which is the one of the shareholder of the electricity generation and distribution in the northern region, comes entirely under the umbrella of the Ministry of public Works, since it was this ministry alone who but time and money in the revival of the power plant and the main grid systems. SEA possesses and maintains several power plants in the northern region's capital city of Hargeisa and the port city of Berbera. SEA is the only state-owned and operated power generating and distributing companies in the northern region, but in the northern capital city of Hargeisa it only provides less than 5% of the customers there but it has significant presence in Berbera. The Ministry of Energy and Minerals Resources of Somaliland does not function properly because of the lack of competent staff; therefore, it does not have the necessary tools to oversee and control the energy sector.

2. ENERGY SECTORS

2.1 Biomass

During the two-decade long period of chaos and lawless, illegal firewood and charcoal exportations became very high in Somalia. the perpetrators cut down millions of trees in Somaliland, Puntland and Southern parts of Somalia and brought the country's farming capability, which was already sparse and slow growing, to a near halt and caused irreparable damages to the environment. Every government administration voiced their concerns about this dire situation and mentioned time and again to stop this shameful act by introducing policies that would prioritize the search of alternative sources to charcoal in all southern cities including Mogadishu. They argued that the main reason for this problem is the country need of charcoal supply for heat. In the central and northern cities, the situation is more serious when compared to the southern regions; because those regions have been experiencing a considerable deforestation and the governments there vowed to put this issue at the top list of their agendas. It is becoming self-evident that the environmental problems facing the country is just as important as every other challenges Somalia faces as it works to rebuild and better their citizens live. In every region of the country, deforestation cause the once fertile lands of Somalia to dry up and slow down the food production of the entire country. Every year millions of rural residents are forced to leave their homes and seek shelter and food in the urban areas. Residents sometimes walk a great distance to find water sources for themselves, their families and their livestock's. Some regional governments are beginning to take the initiative in stopping the use of charcoal by investing more in much cleaner and environmentally friendly heat sources and encourage the public to shift their needs of heat source from charcoal. The Energy ministry in Somaliland, in the 2010 and after, started a great movement advocating for the use of kerosene as a cooking fuel). The regional administration of Puntland also took on the initiative of promoting alternative heat sources by presenting its residents to use

Liquid Petroleum Gas (LPG). But as for the southern cities, although they are aware of these of these dire situations the public is still not sold on the idea of an alternative heat source to charcoal. The federal government introduced policies for alternative heat sources, discussion have been but still the idea hasn't taken ground like it did in Somaliland and Puntland. May be the federal and regional government could lay the blame solely on the southern regional governments not undertaking the necessary initiatives to convince and provide the public with alternative heat sources; but the federal government itself needs to provide these administrations with the tools and the capital for such a massive undertaking.

2.2 Electric Power

Table 2.1: Installed generation Capacity and connections: all Somalia [1]

Area	Installed Capacity(kW)	Number of connections	Power per connection (W)
Mogadishu/Benadir	29,730	120,850	243
Central state	6,610	16,000	413
Hiran & lower shabelle	3,050	8,115	376
South-west state	4,064	7,500	542
Juba state	2,400	12,500	192
Puntland state	11,375	19,535	582
Somaliland state	46,535	85,500	544
Total	103,404	270,000	383

Mogadishu and Southern Somalia

The electrical sources of Somalia, which mainly uses the traditional diesel fueled generators, has not done any or so progression in the last couple of decades. After the overthrow of the government the power production and distribution heavily relied on small private companies with a few generators to serve as much customers as their system would allow. Such systems do not have the wiggle room for improvement. These companies measure the power they provide their customers with Chinese mechanical meters that are not of best quality as reported by Ministry of energy in Somaliland that over one-third of these meters could not function properly once connected [1]. Table 1. Demonstrated the entire system. This table, which was done in 2014, although it's data cannot fully be considered it can give some clear information about how much electricity is generated in Somalia also how many of the residents in each region have access to electricity. These number are clearly blown out of proportion and can be considered as an insufficient data because of the surveyor's inaccessibility to some major cities because of security issues. Also, they stated that the handful of electricity providing companies have provided them with some data but once they contact with the government officials the numbers, they got didn't match the data they had. Some regional government officials didn't provide them with data as they have not done any research on the subject. It suggests that in Table 1. close to 2 out 10 million have access to electricity.

The quality of electricity is very low since there are now grid systems in the cities and power suppliers relay direct wiring from generators to their customers' home or places of work. As demonstrated in the table above the people who live in the northern region have the most access to electricity when compared to rest with Hargeisa having roughly about 75% of and Garowe 40-65% of the population. The table shows that about 33% of Mogadishu's residents have access to electricity [1]. The reason why the people in the north seem to higher access is to electricity is because there is or no oversight over the electrical proving companies and they do as the please and the quality of the electricity compared to Mogadishu is not up to standard. The Electricity in Somalia is much more expensive compared to its neighboring countries and Africa as a whole and that Somalia has higher tariff rating than those countries. The federal government didn't consider the subject of higher tariffs with the international community. The average per kWh in Somalia costs about USD 0.80-1.2/kWh for single phase supply. To sum up, there is not much of a profit in the electricity generation of Somalia under these conditions. The techniques they use for distribution is old and outdated and causes significant power losses to the electricity providers and very poor and expensive electricity for the public. It long past time to say now something must be done and the federal government is realizing clearly the obstacles the country faces in terms of development.

North: Somaliland and Puntland areas:

Although the SEA government agency in Somaliland claims the generated power to be about 70MW actual picture of that situation is far grimmer [1]. The figure stated in the above is very optimistic but not the truth because SEA mainly considers the residents of Hargeisa and the areas close to it. People living at the border with Ethiopia say they get their electricity from the other side of the border. There are no grid interconnections between the cities of Somaliland and clearly the one with grid is SEA with operates 15KV line grid [1]. But as we mentioned in the section above SEA doesn't get the lion's share of the electricity profits from the people in the north. In the section of Puntland's installation capacity is not accurate since there are basically no reliable data that could be stated. For all intents and purposes, Somalia's Electricity generation is so backwards that the federal and regional governments must not give the full control of power supply to private companies. It is self-evident that the power generation of Somalia didn't do small or any progression whatsoever in the last couple of decades when private companies enjoyed full access to it; this was pointed out during a debate that took place in Garowe about the nature of private companies and how they operated. In Puntland alone private companies argued that their services are completely provided by them and that they are giving away free electricity to the government offices and mosques. The government pointed out that it was firsthand the sole provider of those utilities to the private companies by giving them freely the generators they used and that they were not indebted to private companies by getting this electricity. Additionally, the government argued that it provides the diesel cost of the free power given to the mosques and the public offices. The argument concluded that the government must pass legislations to maintain control and bring order to the electric industry and that private companies must not be given a full monopoly in the sector. That is all said, but the political system in Somalia is so corrupt that these government agencies themselves are the ones to blame by taking donations from the already established companies in return for their support in aiding the private investors maintain a full monopoly; sometimes by chasing away some new and innovative companies from those regions, which could benefit the public greatly by bringing in competition to the dominant companies and supplying the residents with cheaper and more effective electricity. Therefore, in order have competitive power generation industry there needs to be a well-established rules and regulations that govern both public and private sector or even to set up a joint venture that includes all different types of sectors. After the 2010, some these standalone private companies started came to the realization that competition is inevitable with the introduction of lights to the streets of the main cities like Mogadishu and Hargeisa and agreed to come together and join their efforts by putting more capital in improving their services or at least discourage any further competition. They are now supporting the government's efforts improve the security situation in the major cities so that more outside investments could be secured. The government is also willing to let in private investments from foreign companies as there are two Turkish companies controlling both the port and the airport of the capital. These signs of development are expected to continue, and security will improve, particularly if the international community kept on backing the government. Although most of the foreign investments made in Somalia mainly goes to the government, sometimes it misses out on more groundbreaking investments to the regional governments like Puntland and Somaliland such as the electrical generation because of an uncertain security.

2.3 Petroleum Products

In Somalia petroleum products ae used almost everywhere. The transportation system in Somalia entirely runs on petrol, so as the almost every electricity generation, which almost all the electricity is from diesel fueled generators. Also, in the last decade Somali people started using petroleum as an alternative to charcoal for cooking and heating. Although it is popular in Somalia, when compared to other energy sources, makes up over 11% of the overall energy used [1]. The price of petroleum in Somalia has been mainly consistent with the global prices and this may be due to the federal and regional governments not putting higher tax rates for the import of petroleum. In some parts of the country the use of kerosene and LPG has become most popular in the last decade and that is due to the deforestation epidemic the country is facing. In the last five years' liquid petroleum gas started to gradually appear in the markets of the capital city Mogadishu and started to gain ground but before that only main cities in Puntland like Garowe and Qardho had access to it. Kerosene isn't lagging LPG and it also gaining customers from Mogadishu and with some rural residents.

2.4 Renewable Energy

Solar

After 2010 the streets of capital city Mogadishu and some other major cities started to install solar generated lambs to lights their cities. There is a great potential use for Solar Energy as Somalia is located near the equator, and some parts of the country are even on the equator. Somalia seasons doesn’t change drastically since there is no snowing there and only the months between May-September enjoy little rain. Researchers found that Somalia has 320 out 365 days of sun which the idea situation for solar energy. But because of poverty and lack of information it had not fully taken advantage of this situation. More and more people every day are realizing this opportunity and hopefully soon they will harness this energy.

Wind

Somalia also has a great potential for producing wind generated electricity. Somalia has a coastal line from the border with Djibouti in north east all the way down to the border with Kenya in south western region. The USAID estimated that Somalia has the highest wind generating capability and once fully harnessed this energy could generate up to 50,000 MW.

Hydro

Unlike Solar and Wind, Somalia doesn’t have a great potential to produce electricity from Hydroelectric sources. Somalia has two rivers Shabelle which starts from the highlands of Ethiopia and runs all the ways down to the south eastern regions of the country and Jubba river which starts from Somalia’s border with Ethiopia and goes all the ways down to the most southern region of the Somalia. That is not to say the country doesn’t have hydroelectric potential, but estimates show that it is significantly smaller potential compared to Solar and Wind energy potentials.

3. METHODOLOGY

3.1 Methodology

3.1.1 VIKOR Method

VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) which translates to Multicriteria Optimization and Compromise Solution was first introduced by Serafim Opricovic in 1998. [7] The VIKOR method was introduced as one applicable technique to be implemented within MCDM problem and it was developed as a multi criteria decision making method to solve a discrete decision-making problem with non-commensurable (different units) and conflicting criteria. This method focuses on ranking and selecting from a set of alternatives and determines compromise solution for a problem with conflicting criteria, which can help the decision makers to reach a final solution. The multi-criteria measure for compromise ranking is developed from the L_p – *metric* used as an aggregating function in a compromise programming method. If each alternative is evaluated according to each criterion function, the compromise ranking could be performed by comparing the measure of closeness to the ideal alternative. The various m alternatives are denoted as A_1, A_2, ..., A_m. For alternative A_i, the rating of the jth aspect is denoted by f_{ij} (i =1, 2..., m; j = 1, 2..., n), i.e., f_{ij} is the value of *jth* criterion function for the alternative A_i, n is the number of criteria [7]. Development of the VIKOR method is started with the following form of L_P - *metric*:

$$L_{p,i}=\{\textstyle\sum^{n}_{j=1}[w_j(f_j^{*}- f_{ij})/(f_j^{*}-f_j^{-})]^p\}^{1/p} \tag{1}$$

In the VIKOR method $L_{1,i}$ (as S_i) and $L_{\infty;i}$ (as R_i) are used to formulate ranking measure [9]. The solution obtained by min S_i is with a maximum group utility (‘‘majority’’ rule), and the solution obtained by min R_i is with a minimum individual regret of the opponent.

The compromise ranking algorithm of the VIKOR method has the following steps:

Normalize the data by using this equation

$$f_{ij} = \frac{Iij}{\sqrt{\sum_{i=1}^{m}(Iij)^2}} \tag{2}$$

$i=1, 2,\ldots,m$, $j=1,2,\ldots,n$

where m is the number of alternatives

Determine the best f_i^* and the worst f_j^-values of all criterion functions j = 1,2,...,n. If the jth function represents a benefit, then

$$f_j^* = max_i f_{ij} \ , \quad f_j^- = min_i f_{ij} \tag{3}$$

Compute the values S_i and R_i ; i = 1,2,....,m, by these relations:

S_i is the utility measure of the attributes

R_i is the regret measure of the attributes

$$S_i = \sum_{j=1}^{n} wj\left(\frac{fj*-fij}{fj*-fj-}\right) \tag{4}$$

for beneficial attributes

$$S_i = \sum_{j=1}^{n} wj\left(\frac{fij-fj-}{fj*-fj-}\right) \tag{5}$$

for non-beneficial attributes

$$R_i = max_j w_j\ (f_j^* - f_{ij})/(\ f_j^*-f_j^-) \tag{6}$$

for beneficial attributes

$$R_i = max_j w_j\ (f_{ij} - f_j^-)/(\ f_j^*-f_j^-) \tag{7}$$

for non-beneficial attributes

where w_j are the weights of criteria, expressing their relative importance.

Compute the values Q_i; i = 1,2,....,m, by the following relation:

$$Q_i = v\ (S_i - S^*)/(S^- - S^*) + (1-v)\ (R_i - R^*)/(R^- - R^*) \tag{8}$$

Where

$$S^* = min_i S_i S^- = max_i S_i \quad [9] \tag{9}$$

$R^* = min_i R_i\ R^- = max_i R_i$

where v is introduced as weight of the strategy of ‘‘most criteria’’ (or ‘‘the maximum group utility’’), normally *v* is between *0-1* but here supposes $v = 0.5$

Rank the alternatives, sorting by the values *S*, *R* and *Q* in decreasing order. The results are three ranking lists.

Propose as a compromise solution the alternative *A’*, which is ranked the best by the measure *Q* (Minimum) if the following two conditions are satisfied:

C1. Acceptable advantage: $Q(A'') - Q(A') \geq DQ$ where *DQ* is the alternative with second position in the ranking list by *Q*. $DQ = 1/(m - 1)$, *m* is the number of alternatives. [9]

C2. Acceptable stability in decision making: Alternative *A*’’ must also be the best ranked by *S* or/and *R*. This compromise solution is stable within a decision-making process, which could be ‘‘voting by majority rule’’ (when $v > 0.5$ is needed), or ‘‘by consensus’’ $v \approx 0.5$, or ‘‘with veto’’ ($v < 0.5$). Here, *v* is the weight of the decision-making strategy ‘‘the majority of criteria’’ (or ‘‘the maximum group utility’’). [9]

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of: [9]

Alternatives *A*’’ and *A*’’ if only condition C2 is not satisfied, or Alternatives *A*’’; *A*’’,.... $A^{(M)}$ if condition *Cl* is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A'') > DQ$ for maximum *M* (the positions of these alternatives are ‘‘in closeness’’).

The best alternative, ranked by Q, is the one with the minimum value of Q. The main ranking result is the compromise ranking list of alternatives, and the compromise solution with the ‘‘advantage rate’’. VIKOR is an effective tool in multi-criteria decision making, particularly in a situation where the decision maker is not able or does not know to express his/her preference at the beginning of system design. The obtained compromise solution could be accepted by the decision makers because it provides a maximum ‘‘group utility’’ (represented by min S) of the ‘‘majority’’, and a minimum of the ‘‘individual regret’’ (represented by min R) of the ‘‘opponent’’. The compromise solutions could be the basis for negotiations, involving the decision maker's preference by criteria weights.

3.2 TOPSIS Method

Technique for Order Preference by Similarity to Ideal Solution or as it normally called TOPSIS is presented in Chen et al. [14], with reference to Huang and Yoon [15]. The basic principle is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution.

In this method two artificial alternatives are hypothesized: Ideal alternative: the one which has the best level for all attributes considered. Negative ideal alternative: the one which has the worst attribute values. TOPSIS selects the alternative that is closest to the ideal solution and farthest from negative ideal alternative. 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 [16]. Let x_{ij} score of option i with respect to criterion j. The score is to be selected between 0 to 9. Now form a matrix X = (x_{ij}) [m x n] matrix. Let J be the set of benefit attributes or criteria (more is better). Let J' be the set of negative attributes or criteria (less is better).

Step 1: The normalized decision matrix is established by using the formula below:

$$r_{ij}= x_{ij} / (\Sigma_i x_i^2 j)^{1/2} \text{ for } i=1 \ldots, m; j=1,\ldots,n \text{ [8]} \quad (10)$$

And normalized matrix is, R_{ij}= (r_{ij}), which is a [m x n] matrix.

Step 2: The weighted normalized decision matrix is determined by multiplying each column of the normalized decision matrix by its associated weight. An element of the new matrix becomes:

$$v_{ij}= w_j r_{ij} \text{ [8]} \quad (11)$$

Where, wj denotes the weight.

Step 3: The ideal and negative ideal solutions is determined in the following manner:

Ideal solution:

$$A^* = \{v1^*, \ldots, vn^*\}. \text{ [8]} \quad (12)$$

Negative ideal solution:

$$A' = \{v1', \ldots, vn'\}.\text{[8]} \quad (13)$$

Where

$$vi^* = [max\ (v_{ij})\_if\_j\in J;\ min(v_{ij})\_if\_j\in J']\ i \text{ [8]} \quad (14)$$

$$vi^- = [min\ (v_{ij})\_if\_j\in J;\ max(v_{ij})\_if\_j\in J']\ i \text{ [8]} \quad (15)$$

Step 4: The separation measures for each alternative is calculated:

The separation from the ideal alternative is:

$$Si\ ^* = [\ \textstyle\sum_j (v_j\ ^*- v_{ij})^2]\ ½\ i = 1,\ldots, m. \quad \text{[8]} \quad (16)$$

Similarly, the separation from the negative ideal alternative is:

$$S'i = [\ \textstyle\sum_j (v_j\ '- v_{ij})^2]\ ½\ i=1,..,m. \quad (17)$$

Step 5: Calculate the relative closeness to the ideal solution Ci*.

$$Ci^* = S'i\ /\ (Si^* + S'i\ )\ ,0 < Ci^* < 1 \text{ [8]} \quad (18)$$

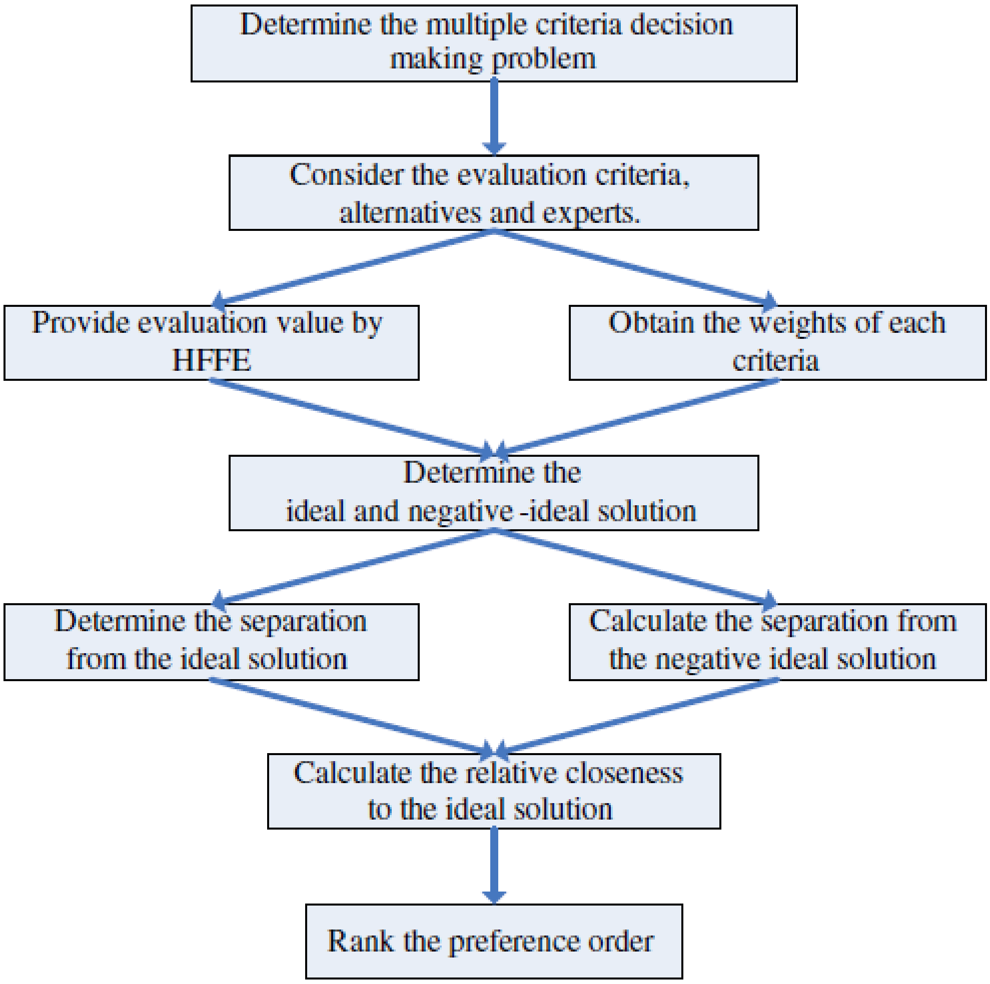

Figure 3.1: Procedure of the TOPSIS Methodology [7]

3.3 Weighted Sum Method

Weighted Sum Method, or in short WSM, developed by Fishburn in 1967 is one of the oldest MCDM methods. WSM's simple computations made it attractive for decision makers to utilize it certain areas such as structural optimation and energy planning. Because of its basic estimates, it has been pointed out that the method fails when it comes to more complicated problems as it cannot take in consideration multiple preferences integrated together. In the of WSM it is relatively straight forward.

Step 1: After setting up the matrix with all the alternatives and the criterions and assigning each criterion with its own weight. First, calculate the maximum and the minimum element in each column.

$$X_j^* = max_j f_{ij} X_j^- = min_j f_{ij} \quad (19)$$

i= 1, 2,..., m and j= 1,2,….., n

Step 2: Then we normalize that matrix by diving each element of the matrix with the maximum number of that column and setting up the normalized decision matrix.

$$R_{ij} = \frac{fij}{Xj*} \quad (20)$$

i= 1, 2,..., m and j= 1,2,….., n

Step 3: Then create a new matrix called weighted matrix. It is done by multiplying each element in the normalized matrix with the weight of that column.

$$Y_{ij} = R_{ij} * W_j \quad (21)$$

Where W_j is the weight value

Step 4: Calculate the performance score of each row in the weighted matrix by adding all the elements in each row.

$$PS= \sum_{i=1}^{n} Yi \quad (22)$$

Step 5: Finally, we rank the alternatives according to their performance scores. The alternative which has a performance score that is close to ‘1’ will be chosen as the number one choice.

3.4 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP), developed by Thomas L. Saaty in 1971-1975, is one of the most important multi criteria decision making techniques. It is also used in planning, resource allocation and conflict resolution problems [1-6]. It uses a hierarchical structure to define the problem by constructing ratio scales from both discrete and continuous paired comparison matrix. AHP, in summary, is a non-linear framework for carrying out both deductive and inductive thinking without the use of logic by considering several factors at the same time and allowing for dependence and for feedback and making numerical tradeoffs to reach the final decision or conclusion. To use AHP for problem solving one needs a hierarchic or network structure to establish that certain problem and form a pairwise comparison matrices to define the relations within the structure. The matrices are always positive and reciprocal e.g. $a_{ij} = 1/a_{ij}$. In short, a hierarchical model, when considering a large-scale societal problem, could be one that descends from an overall objective, down to criteria, down further to sub-criteria which are mainly the subdivisions of the criteria and finally to alternatives from which the choice is made [17].

AHP steps [8]

Step 1: The Criteria and Decision Alternatives are listed.

Step 2: A Pairwise Comparison Matrix is formed where numeric ratings from 1-9 can be assigned as show in Table 2. A reciprocal rating is assigned when second alternative is preferred to first. Numeric rating 1 is assigned when the alternative is compared to itself (see matrix 1.).

Step 3: A Normalized Matrix is developed by dividing each number in a column of the pairwise comparison matrix by its column sum.

$$R_{ij} = \frac{fij}{Xj} \tag{23}$$

$i=1, 2,\ldots,m$, $j=1,2,\ldots,n$

Where R_{ij} is the normalized decision matrix and X_j is the sum of every column

Step 4: The Priority Vector is then evaluated by taking the average of each row of the normalized matrix.

Step 5: The Consistency Ratio is then calculated [CI, RI, and CR] [8].

A consistency ratio of less than 0.1 is preferred. For ratios which are greater than 0.1, the subjective input should be re-evaluated [8].

Step 6: Calculation of a Priority Matrix.

The column entries are the priority vectors for each criterion.

Step 7: The Criteria Pairwise Development Matrix is formed by listing the decision alternatives horizontally and criteria vertically. [8]

Step 8: The Overall Priority Vector is calculated by multiplying the criteria priority vector (from step 7) by the priority matrix (from step 6).

Determining the Consistency Ratio

Step 1: For each row of the pairwise comparison matrix, a weighted sum is determined by summing the multiples of the entries by the priority of its corresponding (column) alternative.

Step 2: For each row, its weighted sum is calculated by dividing the priority of its corresponding (row) alternative.

Step 3: The average is determined, λmax, of the results of step 2.

Step 4: The consistency index, CI, is computed of the n alternatives by:

$$CI=(\lambda max-n)/(n-1) \tag{24}$$

Step5: The random index, RI, is determined from the Random Index table introduced by Saaty as shown in table 3

Step 6: The consistency ratio, CR, is determined as follows:

$$CR = CR/RI. \tag{25}$$

Matrix 1. An example of how to model an AHP problem [10]

	A	B	C	D	E	F	G	H
A	1	5	3	7	6	6	1/3	1/4
B	1/5	1	1/3	5	3	3	1/5	1/7
C	1/3	3	1	6	3	4	6	1/5
D	1/7	1/5	1/6	1	1/3	1/4	1/7	1/8
E	1/6	1/3	1/3	3	1	1/2	1/5	1/6
F	1/6	1/3	¼	4	2	1	1/5	1/6
G	3	5	1/6	7	5	5	1	1/2
H	4	7	5	8	6	6	2	1

Table 3.1: Random Index [10]

SI No	**Number of Alternatives (n) Index (RI)**	**Random**
1	3	0.58
2	4	0.90
3	5	1.12
4	6	1.24
5	7	1.32
6	8	1.41

Table 3.2: The Fundamental Scale Developed By Saaty. [10]

Intensity of Importance on Absolute Scale	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective.
3	Moderate Importance of one over other	Experience and judgement strongly favor one activity over another.
5	Essential or Strong Importance	Experience and judgement strongly favor one activity over another.
7	Very Strong Importance	An activity is favored, and its dominance demonstrated in practice.
9	Extreme Importance	The evidence favoring one activity over the other is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between two adjacent judgements	When compromise is needed.
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared to i.	
Rationales	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix.

3.5 Sensitivity Analysis

After computing each method, it is expected that their results are different from each other, so this method determines mathematically which results is the best. In this section I am going to test each alternative with their calculated weights and observe them through their cost. [8].

$$EIi = \alpha \; x \; SFMi + (1 - \alpha) \; x \; OFMi \tag{26}$$

Where

$$OFMi = \frac{1}{\left[\mathrm{OFUi}\ \sum_{i=1}^{n}\left(\frac{1}{OFUi}\right)\right]} \tag{27}$$

OFM is the Objective Factor Measure. OFU is the Objective Factor Utility which is the cost values of alternatives. SFM is the Subjective Factor Measure

[8]. EI is the Energy Index. ‘α’ is the objective factor decision weight, $\alpha \geq 0$ but $\alpha \leq 1$. ‘n’ is the number of alternatives. Using Eq. number (26) Energy Index can be calculated [8]. The choice of α is an important issue, for selection of α depends on the decision-maker’s preference regarding the importance of objective and subjective factor measures. However, the selection procedure may delineate different sets of result for different values of α for the same decision criteria values [8].

3.6 Weight Calculation

Weight calculation is the most important part for every MCDM because a small incorrectness in the weight values can result in the data becoming compromised. Therefore, this time instead of just randomly assigning weights for each criterion we calculate the weights using Standard Deviation method (Jahan et al., 2012) [11]and the process is this

$$\sigma j = \sqrt{\frac{\sum_{i=1}^{m} [rij - rj]2}{m}} \tag{28}$$

i=1,..m and j=1,……,n [11]

Therefore

$$\omega j_{=} \frac{\sigma j}{\sum_{j=1}^{n} \sigma j} [11] \tag{29}$$

Where σj is the standard deviation for *j* and ωj is the weight value for *j*.

3.7 Per Unit System application

Per Unit System application is a new method presented in this thesis. For every MCDM problem related data it is common to see the diversity of the numbers in every alternative. Furthermore, that diversity itself might corrupt the solution and sometimes could result entirely different result that doesn’t match with the objective of the project. Therefore, its proven that using this system to somehow trim down and equate the data and could give us a clear an unbiased result that agrees with the thesis’s objective. Application of this system is very simple as shown below

First, take the raw data as it is and calculate the average of each column

$$X_j = average_j\,(f_{ij}) \tag{30}$$

i= 1, 2,..., m and j= 1,2,….., n

Where f_{ij} is the individual number in every column of the matrix.

Second, create a new matrix by dividing every individual column value with its respective column average

$$R_{ij} = \frac{fij}{Xj} \tag{31}$$

Where R_{ij} is the new equated matrix.

After applying this system into the data all the numbers become equated to one other and summing the value of each column results in the same value.

4. PROPOSAL

This thesis is divided into three different phases to examine correctly which multicriteria decision making (MCDM) techniques is better suited for the development of the Energy sector in Somalia. The MCDM techniques in question are VIKOR, TOPSIS, Weighted Sum Method (WSM) and Analytical Hierarchy Process (AHP). Throughout this thesis the data being utilized as a reference is the combinations of researches done by the European Union and the World Bank on the development of the power systems of Somalia. After their research they proposed six different projects that could be implemented in order to improve Somalia`s energy problems. These projects would act as the first steppingstone in helping the country become fully energy independent. The first phase of this thesis is introducing three scenarios that could affect the end result of these projects. In every scenario all the four MCDM methods mentioned above are implemented. Phase 2, in every MCDM method calculations one of the most important if not the most important aspects of it is getting the weight of each criteria correctly. So, the weights are calculated and then again, the multicriteria decision making techniques are implement, but only one time and only using the calculated weights and compare this result with the phase results. Phase 3, a new system is introduced called Per Unit System applications (not to be confused with the per unit systems in power electronics). This system is easy and straightforward, and with its help the inconsistencies in the data is simplified so that the answer could be as close as possible to the real one.

4.1 Phase 1

Table 4.1: Formation Of The Alternatives [1]

Alternative 1	10 Hybrid Systems (75% Diesel 25% Solar)
Alternative 2	Electrification of 5 cities
Alternative 3	Electrification of 10 cities
Alternative 4	20 Urban Loads
Alternative 5	5 Wind Generators
Alternative 6	100KW Renewable Energy

Table 4.2: Criterions Intended To Measure With The Alternatives [13]

Power (P)	KW
Implementation period (IP)	Years
Operation and Management cost (O&M)	$\$*10^3$/KWh
Useful Life (UL)	Years
Investment Ratio (IR)	$/KWh
Number Connections (NC)	Power Per Connection (PPC)

Table 4.3: Weight Values For Every Scenario

Scenarios	Criterions					
	P	IP	O&M	UL	IR	NC
Planning	0.4	0.3	0.09	0.05	0.11	0.05
Management	0.11	0.09	0.4	0.1	0.1	0.2
Policy	0.11	0.09	0.05	0.35	0.3	0.1

This study is divided into three different sections, first using the projects and the criterions, as shown in table 7, the four multi criteria decision making methods explained in the chapter before, are implemented by introducing three different scenarios such as energy planning, energy management and energy policies to them. For every scenario the criterions are assigned to different weights randomly, as shown in table 6, and then observe the methods for their selection of projects. As mentioned in the introduction section in today's world Energy production plays a crucial role in societies development, and for Somalia to better its economy and overall progress it needs to pay closer attention to its Energy sector. Therefore, the proposed projects will be implemented gradually throughout the country within the next decade. The projects are

Energy Planning:

A. 10 Hybrid Systems (75% Diesel, 25% Solar)

In 2013 SEA energy company which mainly operates in the northern region of the country proposed a project in which they were to build 10 hybrid mini grids. The grids where to generate 100KWp from Solar/Photovoltaic energy sources and produce a 100kVA using traditional diesel generators. The estimation made by the SEA energy company concluded that the cost for the diesel to be around

USD 0.75/liter and the cost of this project is calculated around USD 582.000. The company divided the cost into three sections, first 20% of it would be offered to local investors, secondly 30% of the cost would be borrowed from the World Bank and the remaining 50% would be a grant from the European Union. Using this system, it is concluded that the tariff would be reduced to about USD 0.48/kWh and with sales of 420kWh/day.

Table 4.4: Alternatives And Criterions Set Up

Alternatives	Criterions					
	P	IP	O&M	UL	IR	NC
A1	150	1	10000	15	346	500
A2	4500	1.5	7000	20	1400	5000
A3	9000	3	25000	25	2800	10000
A4	7000	2.5	10000	20	2100	5000
A5	100	0.5	350	10	200	300
A6	100	2	1000	15	1000	800

B. Electrification of 5 cities

In Somalia, before the collapse of the central government in 1991, was a collection of 18 administrative provinces with their own capital cities and the main cities Mogadishu and Hargeisa. This ambitious project proposed the establishment of a well-organized body that would oversee the distribution of electricity throughout five main cities. But it was later realized that in order to expand the electricity supply in those cities further investments must also be put in rebuilding the old grids network systems and improve the generation capacity in agglomerations, basically all regional capitals. The main two agglomerations demand most of the attention to set up new grid network system. The rest of the administrative regions range from small to densely populated cities where a package for typical project could be invested and designed. The cities which was considered for such a project would be those whose security status have been deemed safe and a place where such a program could be implemented. Those cities most likely would be Hargeisa, Garowe, Berbera, Bosaso, Qardho and possibly Mogadishu. Of course, the search for far appropriate cities is not over as there are ongoing talks with local authorities and the communities. This ambitious electricity supply expansion project is expected to result in a situation in which all the mentioned regional capitals would enjoy a practical power supply by the year 2030.

C. Electrification of 10 cities

This program is the extension of the previous proposed plan introduced also by the WB. Some of those connection will be again considered for the main cities like Mogadishu, Hargeisa and Bosaso. The rest will come from the smaller regional capitals.

D. 20 Rural Loads

This program is solely presented for the local people residing the rural areas. The capital invested into this project suggests the installation of 200MW generational capacity, of which 30-40MWp of it mostly comes from renewable energy sources most notably Solar/Photovoltaic energy. Together with an experimental project comprising of 10 hybrids mini grid with a quota of about 5,000 connections mainly in the rural households. The purpose of this project is to bring excellent quality electricity for some many urban houses. This project has the wiggle room to expand and serve more customers due to lower tariffs and the use of advanced sub-transmission/ distribution grids [1]. However, the likelihood of success of this project solely depends on the capabilities of the local authorities and the local population. It is also necessary that the local authorities and their external development partners are capable enough to establish, fund and support and efficient and fully operational Somali Electrification institute. The federal government and other regional administrations must give up some of their authority to an active oversees funded and reinforced organization that will accomplish the goal of greatly empowering the electric power industry. Therefore, the local authorities must not play a central role in this endeavor or work will not be done effectively. In short local authorities could take on a different this time at board seats where they can oversee the implementation of the projects and promote more investment from the donors should the need arises.

E. 5 Wind power generators at Hargeisa Airport

This project was introduced in 2015 by the ministry of Mining, Energy and Water resources in the Somaliland. The plan was to install wind data stations across the whole region to better offer the investors accurate and detailed information about wind power potential. The use of wind power is a gaining ground as a reasonable alternative energy source in Somaliland. The local government there has come to the realization about the exploitation of this great potential in order to help boost and rejuvenate the region's power supply capacity and find an option which cost effective to the traditional diesel generators.

F. 1000KW Renewable Energy to be installed in Garowe Power Plant [1]

The managers of NEC, the privately owned Garowe utility, reported that their project of adding renewable energy to their diesel generation capacity is almost completed: they have replaced their aging diesels with four new sets of 650kVA each and are adding 500kVA of solar/photovoltaic energy and wind turbines with capacity to generate 500kVA. [1]

Energy Management

After the planning here comes the management of those plans, I just mentioned. These plans can only to fruition if there are willing and committed people to undertake such big tasks. In this I am going to summarize the capital that would be needed to pay and manage these projects.

For plan A, the cost of such project would go up to USD 10 million to build and maintain it. This example doesn't conclude the number of customers that could be served but a rough estimation was made. Furthermore, in the case of the tariff for this proposed project In Somalia could turn out to be higher, less dept but also more piece of the pie for the investors, for example USD 0.60-0.70/kWh. An additional amount of USD 10 million must be invested into the program which would be financed to electrify the proposed 10 mini grids, given that the local investors provide 25% of the whole amount which is estimated to be around USD 2.5 million.

For plan B the electrification of 5 cities the estimated cost would be USD 70 million. Although, this approach is the necessary one for the program the probability of its success would profoundly depend on the situation in those local areas and their circumstances, which sometimes more or less, could make the implementation of this project given that the window of opportunity is very narrow. The project's cost is estimated at USD 70 million.

For plan C the electrification of 10 cities the cost estimation for this one is around USD 250 million nearly three times more than the previous one. Once it is put into place it's expected to serve more than 50,000 customers.

For plan D 20 Rural Loads the cost is estimated to about USD 100 million. The capital of the project is stated as 50% of the generation would get 25% contribution from the private investors but not in the case of the mini grids, where the contribution amount is divided to both the generation and grids and the two do not come together in the case of investment. The numbers are mere symbolic as the distribution grid, which relies on low-voltage distribution grid, is the costliest section along with the generation. Because its heavily dependent on local already specified sites and characteristics of the population's density and dispersion.

For plan E Together with the support of USAID, the northern regional government planned to erect five wind turbines worth over USD 350,000 on a wind farm pilot project near the Hargeisa International Airport [1] in order to tackle the region's ongoing energy crises. The project once fully implemented could serve as much as 400-500 customers.

For plan F to build and maintain renewable power plant in Garowe the regional government estimated it would cost around USD 1 million.

Energy Policies and Regulations

As mentioned above Somali's energy sector is dominated by private companies and their monopoly on sector is one the reasons the country lags the state of electrical generation when compared to its neighbors. Some parts of the country these private companies not only do they monopolize the power supply, but they also pressure other independent companies by bribing local government officials and drive them either bankrupt them or even worse drive them out of that territory. Therefore, for these projects to fully come to fruition then a new institute must be established. This institute will have the full authority and mandate to oversee and regulate the energy sector of the whole country. Therefore, more analysis is indeed required for example some ground base facility that is controlled and operated by the federal government. However, the likelihood of success of this project solely depends on the capabilities of the local authorities and the local population. It is also necessary that the local authorities and their external development partners are capable enough to establish, fund and support and efficient and fully operational Somali Electrification institute. The federal government and other regional administrations must give up some of their authority to an active oversees funded and reinforced organization that will accomplish the goal of greatly empowering the electric power industry. Therefore, the local authorities must not play a central role in this endeavor or work will not be done effectively.

4.2 Phase 2

Secondly, the data shown in table 7 is taken and then the weights for each criterion is calculated using Standard Deviation method and once again the methods are computed using the calculated weights and compare the result with the first one.

4.3 Phase 3

Finally, a new system is introduced in order to equate the values in each criterion and then once again calculated the weights and implement the MCDM methods and compare the results. In every part of the calculation, Sensitivity Analysis is done in order to rank the four MCDM methods.

5. SIMULATION

In this chapter all the calculations done are demonstrated and explained. As mentioned in the previous chapter this thesis is divided into three parts. Let's start with introducing three scenarios and assign weights to the criterions randomly, shown in table 6.

5.1 VIKOR Method for planning

In this section the weights are assigned randomly and most of the weight is focused on the first two criterions and they 70/100% of the weights. The reason for that is to study how the result could be affected by the slightest change in the weight values.

First step in normalizing this data is to square the whole of the matrix as indicated in the table below and create new matrix as shown in table 9

Step two: to normalize the matrix equation (2) and after normalization the maximum and the minimum values of each criterion are calculated using equation (3) as indicated in table 10

Table 5.1: Alternatives And Criterions And The Assigned Weights

Alternative	Criterions					
	P	IP	O&M	UL	IR	NC
A1	150	1	1000	15	346	500
A2	4500	1.5	7000	20	1400	5000
A3	9000	3	25000	25	2800	10000
A4	7000	2.5	100000	20	2100	5000
A5	100	0.5	350	10	200	300
A6	100	2	10000	15	1000	800
Weight	0.4	0.3	0.09	0.05	0.11	0.05

Step three: using the equations (4-7) calculate the utility measure and the regret measure of the normalized decision matrix and the results are shown in table 11

Step four: calculate the value of Q using equation (). The value of v is normally taken as 0.5 but, in this case, different values of v are calculated and observed. the results in table 12.

Table 5.2: Square Values Of The Original Data

	P	IP	O&M	UL	IR	NC
A1	22500	1	1000000	225	119716	250000
A2	20250000	2.25	49000000	400	1960000	25000000
A3	81000000	9	6.25e+08	625	7840000	1e+08
A4	49000000	6.25	1e+10	400	4410000	25000000
A5	10000	0.25	122500	100	40000	90000
A6	10000	4	1e+08	225	1000000	640000

Step 5: ranking the alternatives and selecting the one close to the value 1 as the first and the farthest from it as the last one.

Table 13 shows the ranking of the alternatives in VIKOR. As seen above, the shows slight conflict only in the case of v=0.1 and the rest is the same. Since that value of v is so small and the rest of the values agree we can ignore it and record the rankings of the other values.

Table 5.3: Normalized Decision Matrix

	P	IP	O&M	UL	IR	NC
A1	0.012236	0.209657	0.009634	0.337526	0.088256	0.040692
A2	0.367066	0.314485	0.067435	0.450035	0.357104	0.406921
A3	0.734131	0.628971	0.24084	0.562544	0.714209	0.813842
A4	0.570991	0.524142	0.963361	0.450035	0.535656	0.406921
A5	0.008157	0.104828	0.003372	0.225018	0.051015	0.024415
A6	0.008157	0.419314	0.096336	0.337526	0.255075	0.065107
Max	0.734131	0.628971	0.963361	0.562544	0.714209	0.813842
Min	0.008157	0.104828	0.003372	0.225018	0.051015	0.024415

Table 5.4: Utility Measure And The Regret Measure

	P	IP	O&M	UL	IR	NC	Si	Ri
A1	0.397753	0.06	0.089413	0.033333	0.006177	0.001031	0.587707	0.397753
A2	0.202247	0.12	0.083994	0.016667	0.050769	0.024227	0.497904	0.202247
A3	0	0.3	0.067737	0	0.11	0.05	0.527737	0.3
A4	0.089888	0.24	0	0.016667	0.080385	0.024227	0.451166	0.24
A5	0.4	0	0.09	0.05	0	0	0.54	0.4
A6	0.4	0.18	0.081284	0.033333	0.033846	0.002577	0.731041	0.4

Table 5.5: Calculating Q For Different Values Of V

	Si	Ri	Qi V = 0.1	Qi V = 0.3	Qi V = 0.5	Qi V = 0.7	Qi V = 0.9	Alternative
Max	0.731041	0.4	0.938559	0.838405	0.73825	0.638096	0.537941	A1
Min	0.451166	0.202247	0.156736	0.14001	0.123285	0.10656	0.089834	A2
			0.459722	0.463414	0.467106	0.470798	0.474489	A3
			0.103144	0.102439	0.101734	0.10103	0.100325	A4
			0.929595	0.930076	0.930557	0.931038	0.931519	A5
			1	1	1	1	1	A6

Table 5.6: Ranking Of The Alternatives

Rank V = 0.1	Rank V = 0.3	Rank V = 0.5	Rank V = 0.7	Rank V = 0.9	Alternative
2	3	3	3	3	A1
5	5	5	5	6	A2
4	4	4	4	4	A3
6	6	6	6	5	A4
3	2	2	2	2	A5
1	1	1	1	1	A6

5.2 VIKOR Method for management

In this section all the steps done in the planning is repeated the one change in this matrix is the values of the weights as more weight value is assigned to the operation and management costs (O&M) and the number of connections (NC).

Table 5.7: Alternatives And Criterions And The Assigned Weights

Alternative	P	IP	O&M	UL	IR	NC
A1	150	1	1000	15	346	500
A2	4500	1.5	7000	20	1400	5000
A3	9000	3	25000	25	2800	10000
A4	7000	2.5	100000	20	2100	5000
A5	100	0.5	350	10	200	300
A6	100	2	10000	15	1000	800
Weight	0.11	0.09	0.4	0.1	0.1	0.2

Step 1:

Table 5.8: Square Values Of The Original Data

	P	IP	O&M	UL	IR	NC
A1	22500	1	1000000	225	119716	250000
A2	20250000	2.25	49000000	400	1960000	25000000
A3	81000000	9	6.25E+08	625	7840000	1E+08
A4	49000000	6.25	1E+10	400	4410000	25000000
A5	10000	0.25	122500	100	40000	90000
A6	10000	4	1E+08	225	1000000	640000

Step 2:

Table 5.9: Normalized Decision Matrix

	P	IP	O&M	UL	IR	NC
A1	0.012236	0.209657	0.009634	0.337526	0.088256	0.040692
A2	0.367066	0.314485	0.067435	0.450035	0.357104	0.406921
A3	0.734131	0.628971	0.24084	0.562544	0.714209	0.813842
A4	0.570991	0.524142	0.963361	0.450035	0.535656	0.406921
A5	0.008157	0.104828	0.003372	0.225018	0.051015	0.024415
A6	0.008157	0.419314	0.096336	0.337526	0.255075	0.065107
Max	0.734131	0.628971	0.963361	0.562544	0.714209	0.813842
Min	0.008157	0.104828	0.003372	0.225018	0.051015	0.024415

Step 3:

Table 5.10: Utility Measure And The Regret Measure

	P	IP	O&M	UL	IR	NC	Si	Ri
A1	0.109382	0.018	0.397391	0.066667	0.005615	0.004124	0.601179	0.397391
A2	0.055618	0.036	0.373307	0.033333	0.046154	0.096907	0.641319	0.373307
A3	0	0.09	0.301054	0	0.1	0.2	0.691054	0.301054
A4	0.024719	0.072	0	0.033333	0.073077	0.096907	0.300037	0.096907
A5	0.11	0	0.4	0.1	0	0	0.61	0.4
A6	0.11	0.054	0.361264	0.066667	0.030769	0.010309	0.63301	0.361264

Step 4:

Table 5.11: Calculating Q For Different Values Of V

	Si	Ri	Qi V = 0.1	Qi V = 0.3	Qi V = 0.5	Qi V = 0.7	Qi V = 0.9	Alternative
Max	0.691054	0.4	0.969268	0.925019	0.880771	0.836523	0.792275	A1
Min	0.300037	0.096907	0.874009	0.87574	0.877471	0.879202	0.880934	A2
			0.95887	0.959435	0.96	0.960565	0.96113	A3
			0	0	0	0	0	A4
			1	1	1	1	1	A5
			0.851556	0.851556	0.851556	0.851556	0.851556	A6

Step 5:

Table 5.12: Ranking Of The Alternatives

Rank V = 0.1	Rank V = 0.3	Rank V = 0.5	Rank V = 0.7	Rank V = 0.9	Alternative
2	3	3	5	5	A1
4	4	4	3	3	A2
3	2	2	2	2	A3
6	6	6	6	6	A4
1	1	1	1	1	A5
5	5	5	4	4	A6

5.3 VIKOR Method for policy

In this section all the steps done in the planning is repeated the one change in this matrix is the values of the weights as more weight values are assigned to the Useful Life (UL) and the Investment Ratio (IR).

Table 5.13: Alternatives And Criterions And The Assigned Weights

Alternative	P	IP	O&M	UL	IR	NC
A1	150	1	1000	15	346	500
A2	4500	1.5	7000	20	1400	5000
A3	9000	3	25000	25	2800	10000
A4	7000	2.5	100000	20	2100	5000
A5	100	0.5	350	10	200	300
A6	100	2	10000	15	1000	800
Weight	0.11	0.09	0.05	0.35	0.3	0.1

Step 1:

Table 5.14: Square Values Of The Original Data

	P	IP	O&M	UL	IR	NC
A1	22500	1	1000000	225	119716	250000
A2	20250000	2.25	49000000	400	1960000	25000000
A3	81000000	9	6.25E+08	625	7840000	1E+08
A4	49000000	6.25	1E+10	400	4410000	25000000
A5	10000	0.25	122500	100	40000	90000
A6	10000	4	1E+08	225	1000000	640000

Step 2:

Table 5.15: Normalized Decision Matrix

	P	IP	O&M	UL	IR	NC
A1	0.012236	0.209657	0.009634	0.337526	0.088256	0.040692
A2	0.367066	0.314485	0.067435	0.450035	0.357104	0.406921
A3	0.734131	0.628971	0.24084	0.562544	0.714209	0.813842
A4	0.570991	0.524142	0.963361	0.450035	0.535656	0.406921
A5	0.008157	0.104828	0.003372	0.225018	0.051015	0.024415
A6	0.008157	0.419314	0.096336	0.337526	0.255075	0.065107
Max	0.734131	0.628971	0.963361	0.562544	0.714209	0.813842
Min	0.008157	0.104828	0.003372	0.225018	0.051015	0.024415

Step 3:

Table 5.16: Utility Measure And The Regret Measure

	P	**IP**	**O&M**	**UL**	**IR**	**NC**	**Si**	**Ri**
A1	0.109382	0.018	0.049674	0.233333	0.016846	0.002062	0.429297	0.233333
A2	0.055618	0.036	0.046663	0.116667	0.138462	0.048454	0.441863	0.138462
A3	0	0.09	0.037632	0	0.3	0.1	0.527632	0.3
A4	0.024719	0.072	0	0.116667	0.219231	0.048454	0.48107	0.219231
A5	0.11	0	0.05	0.35	0	0	0.51	0.35
A6	0.11	0.054	0.045158	0.233333	0.092308	0.005155	0.539954	0.233333

Step 4:

Table 5.17: Calculating Q For Different Values Of V

	Si	Ri	Qi V = 0.1	Qi V = 0.3	Qi V = 0.5	Qi V = 0.7	Qi V = 0.9	Alternative
Max	0.539954	0.35	0.403636	0.313939	0.224242	0.134545	0.044848	A1
Min	0.429297	0.138462	0.045836	0.03565	0.025464	0.015279	0.005093	A2
			0.769366	0.768093	0.76682	0.765546	0.764273	A3
			0.448024	0.447914	0.447805	0.447695	0.447586	A4
			0.878724	0.878754	0.878783	0.878813	0.878843	A5
			0.933114	0.933131	0.933147	0.933163	0.93318	A6

Step 5:

Table 5.18: Ranking Of The Alternatives

Rank V = 0.1	Rank V = 0.3	Rank V = 0.5	Rank V = 0.7	Rank V = 0.9	Alternatives
5	5	5	5	5	A1
6	6	6	6	6	A2
3	3	3	3	3	A3
4	4	4	4	4	A4
2	2	2	2	2	A5
1	1	1	1	1	A6

5.4 TOPSIS Method for planning

In every MCDM techniques the first step always is to normalize the data in hand and TOPSIS is not different. Using table 8 as a reference the TOPSIS method is computed for energy planning.

Step 1

Using equation (10) the matrix is normalized, and the result is shown in table 26

Step 2

Using equation (11) create a new matrix by multiplying the normalized decision matrix with the assigned weights as shown in table 27

Step 3

determine the ideal and the negative solutions using equation (17 & 18) as shown in the table 27

Step 4

Calculate the separation measures of the alternatives using the equations (14 & 15) then using equation (16 & 17) the relative closeness to the ideal solution is calculated using equation (18) and in the end the alternatives are ranked to their closeness of the value 1. The result is shown in table 28

Table 5.19: Normalized Decision Matrix

Alternatives	P	IP	O&M	UL	IR	NC
A1	9.98054E-07	0.043956	1.5936E-08	0.007595	2.25118E-05	3.3117E-06
A2	2.99416E-05	0.065934	1.1155E-07	0.010127	9.10882E-05	3.3117E-05
A3	5.98832E-05	0.131868	3.9841E-06	0.012658	0.000182176	6.6234E-05
A4	4.65758E-05	0.10989	1.5936E-07	0.010127	0.000136632	3.3117E-05
A5	6.65369E-07	0.021978	5.5777E-09	0.005063	1.30126E-05	1.987E-06
A6	6.65369E-07	0.087912	1.5936E-07	0.007595	6.5063E-05	5.2987E-06

Table 5.20: Weighted Normalized Matrix, İdeal And Negative Solutions

Alternatives	P	IP	O&M	UL	IR	NC
A1	3.99222E-07	0.013187	1.43426E-09	0.00038	2.4763E-06	1.65585E-07
A2	1.19766E-05	0.01978	1.00398E-08	0.000506	1.00197E-05	1.65585E-06
A3	2.39533E-05	0.03956	3.58565E-07	0.000633	2.00394E-05	3.3117E-06
A4	1.86303E-05	0.032967	1.43426E-08	0.000506	1.50296E-05	1.65585E-06
A5	2.66148E-07	0.006593	5.01991E-10	0.000253	1.43139E-06	9.93509E-08
A6	2.66148E-07	0.026374	1.43426E-08	0.00038	7.15693E-06	2.64936E-07
V+	2.39533E-05	0.006593	3.58565E-07	0.000633	1.43139E-06	9.93509E-08
V-	2.66148E-07	0.03956	5.01991E-10	0.000253	2.00394E-05	3.3117E-06

Table 5.21: Separation Measures, Relative Closeness And Alternative Ranking

Si+	Si-	RC	Rank
0.006598307	0.026373936	0.799882975	2
0.013187429	0.019781846	0.600008521	3
0.032967038	0.000380485	0.011409694	6
0.026373934	0.006598293	0.200116686	5
0.000380485	0.032967038	0.988590306	1
0.019781855	0.013187427	0.39999134	4

5.5 TOPSIS Method for management

Using table 14 as a reference the TOPSIS method is computed for energy management. In this section all the steps done in the planning is repeated the one change in this matrix is the values of the weights as more weight value is assigned to the operation and management costs (O&M) and the number of connections (NC).

Step 1

Table 5.22: Normalized Decision Matrix

Alternatives	P	IP	O&M	UL	IR	NC
A1	9.98054E-07	0.043956	1.5936E-08	0.007595	2.25118E-05	3.3117E-06
A2	2.99416E-05	0.065934	1.1155E-07	0.010127	9.10882E-05	3.3117E-05
A3	5.98832E-05	0.131868	3.9841E-06	0.012658	0.000182176	6.6234E-05
A4	4.65758E-05	0.10989	1.5936E-07	0.010127	0.000136632	3.3117E-05
A5	6.65369E-07	0.021978	5.5777E-09	0.005063	1.30126E-05	1.987E-06
A6	6.65369E-07	0.087912	1.5936E-07	0.007595	6.5063E-05	5.2987E-06

Step 2 & Step 3

Table 5.23: Weighted Normalized Matrix, İdeal And Negative Solutions

Alternatives	P	IP	O&M	UL	IR	NC
A1	1.09786E-07	0.003956	6.37449E-09	0.000759	2.25118E-06	6.62339E-07
A2	3.29358E-06	0.005934	4.46214E-08	0.001013	9.10882E-06	6.62339E-06
A3	6.58716E-06	0.011868	1.59362E-06	0.001266	1.82176E-05	1.32468E-05
A4	5.12334E-06	0.00989	6.37449E-08	0.001013	1.36632E-05	6.62339E-06
A5	7.31906E-08	0.001978	2.23107E-09	0.000506	1.30126E-06	3.97404E-07
A6	7.31906E-08	0.007912	6.37449E-08	0.000759	6.5063E-06	1.05974E-06
V+	6.58716E-06	0.001978	1.59362E-06	0.001266	1.30126E-06	3.97404E-07
V-	7.31906E-08	0.011868	2.23107E-09	0.000506	1.82176E-05	1.32468E-05

Step 4

Table 5.24: Separation Measures, Relative Closeness And Alternative Ranking

Si+	*Si-*	*RS*	*Rank*
0.002041809	0.007916163	0.794957321	2
0.00396415	0.00595564	0.600379606	3
0.009890133	0.000759523	0.071319043	6
0.00791615	0.00204182	0.205043835	5
0.000759523	0.009890133	0.928680957	1
0.005955634	0.003964172	0.399621932	4

5.6 TOPSIS Method for policy

Using table 20 as a reference the TOPSIS method is computed for energy policy. In this section all the steps done in the planning is repeated the one change in this matrix is the values of the weights as more weight value is assigned to the Useful Life (UL) and the Investment Ratio (IR).

Step 1

Table 5.25: Normalized Decision Matrix

Alternatives	P	IP	O&M	UL	IR	NC
A1	9.98054E-07	0.043956	1.5936E-08	0.007595	2.25118E-05	3.3117E-06
A2	2.99416E-05	0.065934	1.1155E-07	0.010127	9.10882E-05	3.3117E-05
A3	5.98832E-05	0.131868	3.9841E-06	0.012658	0.000182176	6.6234E-05
A4	4.65758E-05	0.10989	1.5936E-07	0.010127	0.000136632	3.3117E-05
A5	6.65369E-07	0.021978	5.5777E-09	0.005063	1.30126E-05	1.987E-06
A6	6.65369E-07	0.087912	1.5936E-07	0.007595	6.5063E-05	5.2987E-06

Step 2 & Step 3

Table 5.26: Weighted Normalized Matrix, İdeal And Negative Solutions

Alternatives	P	IP	O&M	UL	IR	NC
A1	1.09786E-07	0.003956	7.96811E-10	0.002658	6.75354E-06	3.3117E-07
A2	3.29358E-06	0.005934	5.57768E-09	0.003544	2.73265E-05	3.3117E-06
A3	6.58716E-06	0.011868	1.99203E-07	0.00443	5.46529E-05	6.62339E-06
A4	5.12334E-06	0.00989	7.96811E-09	0.003544	4.09897E-05	3.3117E-06
A5	7.31906E-08	0.001978	2.78884E-10	0.001772	3.90378E-06	1.98702E-07
A6	7.31906E-08	0.007912	7.96811E-09	0.002658	1.95189E-05	5.29872E-07
V+	6.58716E-06	0.001978	1.99203E-07	0.00443	3.90378E-06	1.98702E-07
V-	7.31906E-08	0.011868	2.78884E-10	0.001772	5.46529E-05	6.62339E-06

Step 4

Table 5.27: Separation Measures, Relative Closeness And Alternative Ranking

Si+	*Si-*	*PS*	*Rank*
0.002655775	0.007961696	0.749867419	2
0.004054132	0.006193095	0.604367924	3
0.009890242	0.002658236	0.211837311	6
0.007961636	0.002655808	0.250136282	5
0.002658236	0.009890242	0.788162689	1
0.006193056	0.004054218	0.395638686	4

5.7 Weighted Sum Method (WSM) for planning

The weighted sum method or in short (WSM) is one of the earliest developed MCDM techniques. Using table 8 as a reference the WSM method is computed for energy planning.

Step 1

Using equation (19) calculate the maximum and minimum values of each criterion as show below in table 35

Step 2

Using equation (20) create normalized decision matrix by taking each value in table 34 and dividing it with the maximum value of its column and the result is shown in table 36

Table 5.28: Alternatives, Attributes, Assigned Weights And The Max And Min Values

Alternative	P	IP	O&M	UL	IR	NC
A1	150	1	1000	15	346	500
A2	4500	1.5	7000	20	1400	5000
A3	9000	3	250000	25	2800	10000
A4	7000	2.5	10000	20	2100	5000
A5	100	0.5	350	10	200	300
A6	100	2	10000	15	1000	1000
Max	9000	3	250000	25	2800	10000
Min	100	0.5	350	10	200	300
Weight	0.4	0.3	0.09	0.05	0.11	0.05

Table 5.29: Normalized Decision Matrix

Alternative	P	IP	O&M	UL	IR	NC
A1	0.016667	0.333333	0.004	0.6	0.123571	0.05
A2	0.5	0.5	0.028	0.8	0.5	0.5
A3	1	1	1	1	1	1
A4	0.777778	0.833333	0.04	0.8	0.75	0.5
A5	0.011111	0.166667	0.0014	0.4	0.071429	0.03
A6	0.011111	0.666667	0.04	0.6	0.357143	0.1

Step 3:

Using equation (21) take every value of the normalized decision matrix and multiplied it with weight values of its column and the result is the creation of the weighted decision matrix as shown below. After that calculate the performance score (PS) using equation (22) which is the sum of each row. In the I ranked the alternatives by choosing the 1^{st} alternative as the one closest to 1.

Table 5.30: Weighted Decision Matrix And Ranking Of The Alternatives

	P	IP	O&M	UL	IR	NC	PS	RANK
A1	0.006667	0.1	0.00036	0.03	0.013593	0.0025	0.15312	5
A2	0.2	0.15	0.00252	0.04	0.055	0.025	0.47252	3
A3	0.4	0.3	0.09	0.05	0.11	0.05	1	1
A4	0.311111	0.25	0.0036	0.04	0.0825	0.025	0.712211	2
A5	0.004444	0.05	0.000126	0.02	0.007857	0.0015	0.083928	6
A6	0.004444	0.2	0.0036	0.03	0.039286	0.005	0.28233	4

5.8 Weighted Sum Method (WSM) for management

Using table 14 as a reference the WSM method is computed for energy management. In this section all the steps done in the planning is repeated the one change in this matrix is the values of the weights as more weight value is assigned to the operation and management costs (O&M) and the number of connections (NC).

Step 1

Table 5.31: Alternatives, Attributes, Assigned Weights And The Max And Min Values

Alternative	P	IP	O&M	UL	IR	NC
A1	150	1	1000	15	346	500
A2	4500	1.5	7000	20	1400	5000
A3	9000	3	250000	25	2800	10000
A4	7000	2.5	10000	20	2100	5000
A5	100	0.5	350	10	200	300
A6	100	2	10000	15	1000	1000
Max	9000	3	250000	25	2800	10000
Min	100	0.5	350	10	200	300
Weight	0.11	0.09	0.4	0.1	0.1	0.2

Step 2

Table 5.32: Normalized Decision Matrix

Alternative	*P*	*IP*	*O&M*	*UL*	*IR*	*NC*
A1	0.016667	0.333333	0.004	0.6	0.123571	0.05
A2	0.5	0.5	0.028	0.8	0.5	0.5
A3	1	1	1	1	1	1
A4	0.777778	0.833333	0.04	0.8	0.75	0.5
A5	0.011111	0.166667	0.0014	0.4	0.071429	0.03
A6	0.011111	0.666667	0.04	0.6	0.357143	0.1

Step 3

Table 5.33: Weighted Decision Matrix And Ranking Of The Alternatives

	P	IP	O&M	UL	IR	NC	PS	RANK
A1	0.001833	0.03	0.0016	0.06	0.012357	0.01	0.11579	5
A2	0.055	0.045	0.0112	0.08	0.05	0.1	0.3412	3
A3	0.11	0.09	0.4	0.1	0.1	0.2	1	1
A4	0.085556	0.075	0.016	0.08	0.075	0.1	0.431556	2
A5	0.001222	0.015	0.00056	0.04	0.007143	0.006	0.069925	6
A6	0.001222	0.06	0.016	0.06	0.035714	0.02	0.192937	4

5.9 Weighted Sum Method (WSM) for policy

Using table 20 as a reference the TOPSIS method is computed for energy policy. In this section all the steps done in the planning is repeated the one change in this matrix is the values of the weights as more weight value is assigned to the Useful Life (UL) and the Investment Ratio (IR).

Step 1

Table 5.34: Alternatives, Attributes, Assigned Weights And The Max And Min Values

Alternative	P	IP	O&M	UL	IR	NC
A1	150	1	1000	15	346	500
A2	4500	1.5	7000	20	1400	5000
A3	9000	3	250000	25	2800	10000
A4	7000	2.5	10000	20	2100	5000
A5	100	0.5	350	10	200	300
A6	100	2	10000	15	1000	1000
Max	9000	3	250000	25	2800	10000
Min	100	0.5	350	10	200	300
Weight	0.11	0.09	0.05	0.35	0.3	0.1

Step 2

Table 5.35: Normalized Decision Matrix

Alternative	P	IP	O&M	UL	IR	NC
A1	0.016667	0.333333	0.004	0.6	0.123571	0.05
A2	0.5	0.5	0.028	0.8	0.5	0.5
A3	1	1	1	1	1	1
A4	0.777778	0.833333	0.04	0.8	0.75	0.5
A5	0.011111	0.166667	0.0014	0.4	0.071429	0.03
A6	0.011111	0.666667	0.04	0.6	0.357143	0.1

Step 3

Table 5.36: Weighted Decision Matrix And Ranking Of The Alternatives

	P	IP	O&M	UL	IR	NC	PS	RANK
A1	0.001833	0.03	0.0002	0.21	0.037071	0.005	0.284105	5
A2	0.055	0.045	0.0014	0.28	0.15	0.05	0.5814	3
A3	0.11	0.09	0.05	0.35	0.3	0.1	1	1
A4	0.085556	0.075	0.002	0.28	0.225	0.05	0.717556	2
A5	0.001222	0.015	0.00007	0.14	0.021429	0.003	0.180721	6
A6	0.001222	0.06	0.002	0.21	0.107143	0.01	0.390365	4

5.10 Analytical Hierarchy Process (AHP) Method for planning

The Analytical Hierarchy Process or AHP is totally different from the other three methods we have seen above. Instead of taking the raw data as it is the AHP process starts with the creation of a piece-wise comparison matrix as indicated in (Matrix 1 in page 26). The matrix can be created following Saaty's table of the fundamental scale (as shown in table 3 in page 27). Using AHP requires so many computations

Step 1

Create piece-wise comparison matrix following Saaty's table of the fundamental scale and then sum the values as shown in table 44.

Step 2

Normalize the pairwise comparison matrix using equation (23) by dividing each number in the column with its respective total value and the sum the values of the rows and take the new column as the new calculated weights of each criterion as shown in table 45.

Step 3

Take the pairwise comparison matrix and multiply it with the criteria weights column then sum the values in the rows and create the new column weighted sum. After that calculated the consistency of the matrix by dividing the weighted sum column with the criteria weight's column. The results are shown below in table 45.

Step 4

Calculate the average value of the consistency and the calculate the consistency index (CI) by using equation (24), after that using the random index in table 3 calculate the consistency ratio (CR) of the matrix using equation (25). As stated by Saaty the CR must be equal or smaller than 0.1. The result is shown below

Table 5.37: Pairwise Comparison Matrix And Their Total Values

Criteria	P	IP	O&M	UL	IR	NC
Weights	0.4	0.3	0.09	0.05	0.11	0.05
P	1	2	2	6	4	3
IP	0.5	1	3	5	0.5	2
O&M	0.2	0.33	1	2	0.33	2
UL	0.167	0.2	0.5	1	0.5	2
IR	0.25	2	3	2	1	2
NC	0.33	0.5	0.5	0.5	0.5	1
Total	2.447	6.03	10	16.5	6.83	12

Table 5.38: Normalized Decision Matrix Of The Pairwise Comparison

	P	IP	O&M	UL	IR	NC	Criteria Weights
P	0.408664	0.331675	0.2	0.363636	0.585652	0.25	0.356604422
IP	0.204332	0.165837	0.3	0.30303	0.073206	0.166667	0.202178788
O&M	0.081733	0.054726	0.1	0.121212	0.048316	0.166667	0.095442357
UL	0.068247	0.033167	0.05	0.060606	0.073206	0.166667	0.075315583
IR	0.102166	0.331675	0.3	0.121212	0.146413	0.166667	0.194688758
NC	0.134859	0.082919	0.05	0.030303	0.073206	0.083333	0.075770093

Table 5.39: Weighted Normalized Decision Matrix And Consistency

	P	IP	O&M	UL	IR	NC	WEIGHTED SUM	CONSISTENCY (CV)
P	0.356604	0.40436	0.190885	0.451893	0.778755	0.22731	2.40980552	6.75764341
IP	0.178302	0.20218	0.286327	0.376578	0.097344	0.15154	1.29227056	6.391721723
O&M	0.071321	0.06672	0.095442	0.150631	0.064247	0.15154	0.59990088	6.285478502
UL	0.059553	0.04044	0.047721	0.075316	0.097344	0.15154	0.47191002	6.26576869
IR	0.089151	0.40436	0.286327	0.150631	0.194689	0.15154	1.27669586	6.557624971
NC	0.117679	0.10109	0.047721	0.037658	0.097344	0.07577	0.47726229	6.298821572

Table 5.40: Average CV, CI And CR

Average CV	Consistency Index (CI)	Consistency Ratio (CR)
6.426176	0.085235	0.068738

Now that the matrix is consistence let's move on to the last step of the calculation.

Step 5:

This new matrix is calculated in Appendix (A), the values of Alternative Priority (AP), which is basically the average of the normalized decision in every row, is used here as the new matrix and call it 'A'. Now take the transpose of this matrix and the multiply it with criteria weights (CW) calculated in (table 45) and created new column (A*CW). The values of this column are then ranked as show in table 48.

Table 5.41: Alternative Ranking

A	A1	A2	A3	A4	A5	A6	A'*CW	Rank
P	0.03924	0.08524	0.32502	0.16098	0.03154	0.35798	0.1419	4
IP	0.2213	0.17526	0.03949	0.06155	0.37188	0.13051	0.1185	5
O&M	0.15365	0.08221	0.02037	0.04083	0.45468	0.24827	0.1989	3
UL	0.07505	0.15269	0.44297	0.17809	0.02386	0.12733	0.1085	6
IR	0.29512	0.08562	0.02281	0.0451	0.425	0.12635	0.2162	1
NC	0.07123	0.22033	0.46514	0.16557	0.02433	0.05339	0.216	2

5.11 Analytical Hierarchy Process (AHP) Method for management

Using the same steps, again compute the data in this section all the steps are same as the one done in the planning are repeated

Step 1

Table 5.42: Pairwise Comparison Matrix And Their Total Values

Criteria	P	IP	O&M	UL	IR	NC
Weights	0.11	0.09	0.4	0.1	0.1	0.2
P	1	2	0.25	2	2	0.5
IP	0.5	1	0.25	0.5	0.5	0.5
O&M	4	4	1	3	3	0.25
UL	0.5	2	0.25	1	2	0.5
IR	0.5	2	0.25	0.5	1	0.5
NC	2	2	4	2	2	1
Total	8.5	13	6	9	10.5	3.25

Step 2

Table 5.43: Normalized Decision Matrix Of The Pairwise Comparison

	P	IP	O&M	UL	IR	NC	Criteria Weights
P	0.117647	0.153846	0.041667	0.222222	0.190476	0.153846	0.146617408
IP	0.058824	0.076923	0.041667	0.055556	0.047619	0.153846	0.072405672
O&M	0.470588	0.307692	0.166667	0.333333	0.285714	0.076923	0.273486318
UL	0.058824	0.153846	0.041667	0.111111	0.190476	0.153846	0.118294968
IR	0.058824	0.153846	0.041667	0.055556	0.095238	0.153846	0.093162692
NC	0.235294	0.153846	0.666667	0.222222	0.190476	0.307692	0.296032943

Step 3

Table 5.44: Weighted Normalized Decision Matrix And Consistency

	P	IP	O&M	UL	IR	NC	Weighted Sum	Consistency (CV)
P	0.146617	0.144811	0.068372	0.23659	0.186325	0.148016	0.930732122	6.348032862
IP	0.073309	0.072406	0.068372	0.059147	0.046581	0.148016	0.467831256	6.461251524
O&M	0.58647	0.289623	0.273486	0.354885	0.279488	0.074008	1.857959851	6.793611713
UL	0.073309	0.144811	0.068372	0.118295	0.186325	0.148016	0.739128451	6.248181692
IR	0.073309	0.144811	0.068372	0.059147	0.093163	0.148016	0.586818274	6.298854821
NC	0.293235	0.144811	1.093945	0.23659	0.186325	0.296033	2.250939692	7.603679741

Step 3

Table 5.45: Weighted Normalized Decision Matrix And Consistency

	P	IP	O&M	UL	IR	NC	Weighted Sum	Consistency (CV)
P	0.146617	0.144811	0.068372	0.23659	0.186325	0.148016	0.930732122	6.348032862
IP	0.073309	0.072406	0.068372	0.059147	0.046581	0.148016	0.467831256	6.461251524
O&M	0.58647	0.289623	0.273486	0.354885	0.279488	0.074008	1.857959851	6.793611713
UL	0.073309	0.144811	0.068372	0.118295	0.186325	0.148016	0.739128451	6.248181692
IR	0.073309	0.144811	0.068372	0.059147	0.093163	0.148016	0.586818274	6.298854821
NC	0.293235	0.144811	1.093945	0.23659	0.186325	0.296033	2.250939692	7.603679741

Step 4

Table 5.46: Average CV, CI And CR

Average CV	Consistency Index (CI)	Consistency Ratio (CR)
6.625602	0.12512	0.100904

Step 5

Table 5.47: Alternative Ranking

A	A1	A2	A3	A4	A5	A6	A'*CW	Rank
P	0.03924	0.08524	0.32502	0.16098	0.03154	0.35798	0.1213	5
IP	0.2213	0.17526	0.03949	0.06155	0.37188	0.13051	0.1389	4
O&M	0.15365	0.08221	0.02037	0.04083	0.45468	0.24827	0.2483	1
UL	0.07505	0.15269	0.44297	0.17809	0.02386	0.12733	0.1135	6
IR	0.29512	0.08562	0.02281	0.0451	0.425	0.12635	0.2055	2
NC	0.07123	0.22033	0.46514	0.16557	0.02433	0.05339	0.1725	3

5.12 Analytical Hierarchy Process (AHP) Method for policy

Using the same steps, again compute the data in this section all the steps are same as the one done in the planning is repeated

Step 1

Table 5.48: Pairwise Comparison Matrix And Their Total Values

Criteria	P	IP	O&M	UL	IR	NC
Weights	0.11	0.09	0.05	0.35	0.3	0.1
P	1	2	3	0.33	0.33	2
IP	0.5	1	2	0.25	0.3	2
O&M	0.33	0.5	1	0.143	0.167	0.5
UL	3	4	7	1	2	4
IR	3	3	6	0.5	1	3
NC	0.5	0.5	2	0.25	0.33	1
Total	8.33	11	21	2.473	4.127	12.5

Step 2

Table 5.49: Normalized Decision Matrix Of The Pairwise Comparison

	P	IP	O&M	UL	IR	NC	CRITERIA WEIGHTS(CW)
P	0.120048	0.181818	0.142857	0.133441	0.079961	0.16	0.13635429
IP	0.060024	0.090909	0.095238	0.101092	0.072692	0.16	0.096659169
O&M	0.039616	0.045455	0.047619	0.057825	0.040465	0.04	0.045163196
UL	0.360144	0.363636	0.333333	0.404367	0.484614	0.32	0.377682407
IR	0.360144	0.272727	0.285714	0.202184	0.242307	0.24	0.267179327
NC	0.060024	0.045455	0.095238	0.101092	0.079961	0.08	0.076961612

Step 3

Table 5.50: Weighted Normalized Decision Matrix And Consistency

3	P	IP	O&M	UL	IR	NC	Weighted Sum	Consistency (CV)
P	0.136354	0.193318	0.13549	0.124635	0.088169	0.153923	0.831889811	6.100943444
IP	0.068177	0.096659	0.090326	0.094421	0.080154	0.153923	0.583660329	6.038333806
O&M	0.044997	0.04833	0.045163	0.054009	0.044619	0.038481	0.275598034	6.102270453
UL	0.409063	0.386637	0.316142	0.377682	0.534359	0.307846	2.331729423	6.173783532
IR	0.409063	0.289978	0.270979	0.188841	0.267179	0.230885	1.656924917	6.201546123
NC	0.068177	0.04833	0.090326	0.094421	0.088169	0.076962	0.466384512	6.059962875

Step 4

Table 5.51: Average CV, CI And CR

Average CV	Consistency Index (CI)	Consistency Ratio (CR)
6.112807	0.022561	0.018195

Step 5

Table 5.52: Alternative Ranking

A	A1	A2	A3	A4	A5	A6	A'*CW	Rank
P	0.03924	0.08524	0.32502	0.16098	0.03154	0.35798	0.1464	4
IP	0.2213	0.17526	0.03949	0.06155	0.37188	0.13051	0.1298	5
O&M	0.15365	0.08221	0.02037	0.04083	0.45468	0.24827	0.2582	1
UL	0.07505	0.15269	0.44297	0.17809	0.02386	0.12733	0.1218	6
IR	0.29512	0.08562	0.02281	0.0451	0.425	0.12635	0.1852	2
NC	0.07123	0.22033	0.46514	0.16557	0.02433	0.05339	0.1586	3

Now the calculations for the MCDM methods are done. As in shown below tables (59-61) demonstrate the ranking of the alternatives by the four methods in every scenario.

Table 5.53: Method Ranking For Energy Planning

Alternative/Method	VIKOR	TOPSIS	WSM	AHP
A1	3	2	5	4
A2	5	3	3	5
A3	4	6	1	3
A4	6	5	2	6
A5	2	1	6	1
A6	1	4	4	2

Table 5.54: Method Ranking For Energy Management

Alternative/Method	VIKOR	TOPSIS	WSM	AHP
A1	3	2	5	5
A2	4	3	3	4
A3	2	6	1	1
A4	6	5	2	6
A5	1	1	6	2
A6	5	4	4	3

Table 5.55: Method Ranking For Energy Policies

Alternative/ Method	VIKOR	TOPSIS	WSM	AHP
A1	5	2	5	4
A2	6	3	3	5
A3	3	6	1	1
A4	4	5	2	6
A5	2	1	6	2
A6	1	4	4	3

Now, apply Sensitivity Analysis method to rank the methods based on the choices each one of them made from the alternatives

5.13 Sensitivity analysis

In this part find the best method for each of the three sections calculated above.

First, calculate Objective Factor Unit or OFU and this value is assigned from original data (power for energy planning, operation and management costs for management and useful life for energy policies). After that a new value called the Objective Factor Measure Index or OFMI is calculated by using equation (27). Then create value called the Subjective Factor measure index or SFMI, this is only the value of the obtained first choice of the alternative in each method. Then, calculate the Energy Index EI value by using equation (26). In equation (26) there is value α and it is between 0-1 and in our case, in this part α is given the value of 0.25. The results are shown in tables 62-64.

Table 5.56: Sensitivity Analysis And Method Ranking For Energy Planning

Methods	Planning				
	A	Subjective factor measure index (SFMI)	P	Energy index (EI)	R
VIKOR	A6	1	100	0.25	1
AHP	A5	0.22	100	0.05	4
TOPSIS	A5	0.73	100	0.18	3
WSM	A3	0.96	9000	0.24	2

Table 5.57: Sensitivity Analysis And Method Ranking For Energy Management

Methods		Management			
	A	Subjective factor measure index (SFMI)	O&M	Energy index (EI)	R
VIKOR	A5	0.98	350	0.24	1
AHP	A3	0.25	250000	0.06	4
TOPSIS	A5	039	250000	0.1	3
WSM	A3	0.66	350	0.16	2

The results from tables 62-64 clearly state that the method to use for such project is VIKOR. In the case of planning the VIKOR method chose the 6th alternative to be the first one to implement but this alternative doesn’t give the most power which is clearly what I am trying to get as much as possible. The second one for management it chose the 5th alternative in this case I am most focused on their costs and thankfully it chose the cheapest one but it not alone WSM also chose this alternative. Lastly, for the energy policies I focused on the projects longevity and VIKOR picked alternative number 6. Although it is not the ideal one when comes to useful life it is not also that bad so for now, I accepted these results.

5.14 Weight Calculation

In every MCDM method the weight of each criterion must be close to perfect or the whole data will be corrupted. Till now, the calculations that was done have been to examine these methods and see how well they could make sense of the data given and each time weights are assigned to the criterions randomly. This time calculate the weights used for these methods using a method called Standard deviation.

Step 1

First, take the transpose of the original matrix and then sum each column as shown in table 65.

Step 2

Next, create a new matrix by taking the value in each column and dividing it with the total value of that column. Then subtract the total value of the rows from the sum of the columns and square the result as show in table 66

Step 3

Calculate the standard deviation of the matrix shown in table 66 by using equation (28) after that I can easily calculated the weights using equation (29) show in the table below

Table 5.58: Transpose Matrix

	A1	A2	A3	A4	A5	A6
P	150	4500	9000	7000	100	100
IP	1	1.5	3	2.5	0.5	2
O&M	1000	7000	25000	10000	350	10000
UL	15	20	25	20	10	15
IR	346	1400	2800	2100	200	1000
NC	500	5000	10000	5000	300	800
Total	2012	17921.5	46828	24122.5	960.5	11917

Table 5.59: Solution From The Transpose Matrix

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*TOTAL*	*(Row-Column) ^2*
P	0.074553	0.251095	0.192193	0.290186	0.104112	0.008391	0.92053	0.006316
IP	0.000497	8.37E-05	6.41E-05	0.000104	0.000521	0.000168	0.001437	2.06E-06
O&M	0.497018	0.390592	0.533869	0.414551	0.364394	0.839137	3.03956	9.238928
UL	0.007455	0.001116	0.000534	0.000829	0.010411	0.001259	0.021604	0.000467
IR	0.171968	0.078118	0.059793	0.087056	0.208225	0.083914	0.689074	0.474823
NC	0.248509	0.278995	0.213547	0.207275	0.312337	0.067131	1.327795	1.763038
Total	1	1	1	1	1	1		

Table 5.60: Standard Deviation And Weight Calculation

Standard Deviation	Weight
0.013245038	0.015404
0.000239468	0.000279
0.506593411	0.589183
0.003600694	0.004188
0.114845702	0.133569
0.221299097	0.257377

5.15 Computing the methods by using the calculated weights

Now compute the MCDM methods again but this time use the weights calculated. In table 68 the calculated weights for each criterion in demonstrated

Table 5.61: Calculated Weights For Each Criterion

	Criterions					
	P	IP	O&M	UL	IR	NC
Weights	0.015404	0.000279	0.589183	0.004188	0.004188	0.257377

The tables below show the results of the MCDM methods, (VIKOR, TOPSIS, WSM and AHP)

Table 5.62: VIKOR Method Ranking Using The Calculated Weights

Alternative	P	IP	O&M	UL	IR	NC	Qi	Rank
A1	0.15313483	0.000056	0.001534	0.002793	0.0075	0.252073	0.278026	4
A2	0.07786517	0.000112	0.015694	0.001397	0.061648	0.13267	0.130778	6
A3	0	0.00028	0.58918	0	0.13357	0	0.630778	1
A4	0.03460674	0.000224	0.235176	0.001397	0.097609	0.13267	0.375561	2
A5	0.154	0	0	0.00419	0	0.25738	0.276271	5
A6	0.154	0.000168	0.022774	0.002793	0.041098	0.238806	0.327085	3

Table 5.63: TOPSIS Method Ranking Using The Calculated Weights

Alternative	P	IP	O&M	UL	IR	NC	PS	Rank
A1	1.547E-07	1.32E-05	9.3893E-09	3.19E-05	3.0069E-06	8.52365E-07	0.617556613	1
A2	4.61101E-06	1.98E-05	6.57251E-08	4.25E-05	1.21667E-05	8.52365E-06	0.598917145	2
A3	9.22202E-06	3.96E-05	2.34733E-06	5.32E-05	2.43333E-05	1.70473E-05	0.434694376	5
A4	7.17268E-06	3.3E-05	9.3893E-08	4.25E-05	1.825E-05	8.52365E-06	0.429664214	6
A5	1.02467E-07	6.59E-06	3.28626E-09	2.13E-05	1.73809E-06	5.11419E-07	0.565305624	3
A6	1.02467E-07	2.64E-05	9.3893E-08	3.19E-05	8.69047E-06	1.36378E-06	0.471017984	4

Table 5.64: WSM Method Ranking Using The Calculated Weights

	P	IP	O&M	UL	IR	NC	PS	RANK
A1	0.002567	0.0001	0.002357	0.00252	0.016509	0.01287	0.036923	5
A2	0.077	0.00015	0.016498	0.00336	0.0668	0.1287	0.292508	3
A3	0.154	0.0003	0.5892	0.0042	0.1336	0.2574	1.1387	1
A4	0.119778	0.00025	0.023568	0.00336	0.1002	0.1287	0.375856	2
A5	0.001711	0.00005	0.000825	0.00168	0.009543	0.007722	0.021531	6
A6	0.001711	0.0002	0.023568	0.00252	0.047714	0.02574	0.101453	4

Table 5.65: AHP Method Ranking Using The Calculated Weights

A	P	IP	O&M	UL	IR	NC	A*CW	Rank
A1	0.03924	0.2213	0.15365	0.07505	0.29512	0.07123	0.194495127	3
A2	0.08524	0.17526	0.08221	0.15269	0.08562	0.22033	0.035776019	6
A3	0.32502	0.03949	0.02037	0.44297	0.02281	0.46514	0.178378893	4
A4	0.16098	0.06155	0.04083	0.17809	0.0451	0.16557	0.090540003	5
A5	0.03154	0.37188	0.45468	0.02386	0.425	0.02433	0.202497531	2
A6	0.35798	0.13051	0.24827	0.12733	0.12635	0.05339	0.31473551	1

Once again calculate the Sensitivity Analysis of the results shown above and result is shown in table 73

Table 5.66: Sensitivity Analysis And Method Ranking With The Calculated Weights

Methods	Alternatives	SFMI	OFU(O&M)	1/OFU	OFMI	EI	Rank
VIKOR	A3	0.608228	250000	0.000004	0.003610108	0.154764581	3
AHP	A6	0.31473551	10000	0.0001	0.090252708	0.146373408	4
TOPSIS	A1	0.573959613	1000	0.001	0.902527076	0.82038521	1
WSM	A3	1.1387	250000	0.000004	0.003610108	0.287382581	2

5.16 Per Unit Systems Application

Per Unit Systems Application is system designed to use for the simplification of complicated problems. In this thesis it is used to simplify the data in hand. Following its two-step calculation, its proven that this system to could somehow trim down and equate the data and give a clear an unbiased result that agrees with the thesis's objective. Application of this system is very simple as shown below

Step 1

Take the original data and calculate the average of each column using equation (30)

Table 5.67: Original Matrix With Average Calculated

Alternative	P	IP	O&M	UL	IR	NC
A1	150	1	1000	15	346	500
A2	4500	1.5	7000	20	1400	5000
A3	9000	3	250000	25	2800	10000
A4	7000	2.5	10000	20	2100	5000
A5	100	0.5	350	10	200	300
A6	100	2	10000	15	1000	800
Total	20850	10.5	278350	105	7846	21600
Average	3475	1.75	46391.67	17.5	1307.667	3600

Step 2

Using equation (30) create a new matrix by dividing every individual column value with its respective column average

Table 5.68: İndividual Column Values Divided With The Average Of İts Column

Alternative	P	IP	O&M	UL	IR	NC
A1	0.043165	0.571429	0.021556	0.857143	0.264593	0.138889
A2	1.294964	0.857143	0.150889	1.142857	1.070609	1.388889
A3	2.589928	1.714286	5.388899	1.428571	2.141218	2.777778
A4	2.014388	1.428571	0.215556	1.142857	1.605914	1.388889
A5	0.028777	0.285714	0.007544	0.571429	0.152944	0.083333
A6	0.028777	1.142857	0.215556	0.857143	0.764721	0.222222
Total	6	6	6	6	6	6

If one observes the total row in table 74 it is easy to see that the sum of the individual column is equal to the number of the alternatives in hand which is 6. Now, using this table calculate new weights, then use the MCDM methods and finally calculate the sensitivity analysis of the results found. In table 75 the new calculated weights are shown. Then the results of the MCDM methods with this matrix are shown in table 76-79 and finally the sensitivity results of the methods and are demonstrated in table 80.

Table 5.69: New Calculated Weights

	Criterions					
	P	IP	O&M	UL	IR	NC
Weights	0.173324	0.003998	0.424128	0.075872	0.205724	0.116954

Table 5.70: Ranking TOPSIS Alternatives

Relative Closeness	Rank
0.739248	3
0.805981	1
0.262594	6
0.78518	2
0.737406	4
0.721981	5

Table 5.71: Ranking VIKOR Alternatives For Different Values Of Q

QI	0.1	0.3	0.5	0.7	0.9	Average	Rank
A1	0.993443383	0.985538	0.977632	0.969727	0.961821	0.977632	2
A2	0.945947948	0.891119	0.836289	0.78146	0.72663	0.836289	4
A3	0	0	0	0	0	0	6
A4	0.924055807	0.849476	0.774896	0.700316	0.625736	0.774896	5
A5	1	1	1	1	1	1	1
A6	0.953870006	0.938918	0.923967	0.909015	0.894064	0.923967	3

Table 5.72: Ranking The Alternatives For Weighted Sum Method

Alternative	P	IP	O&M	UL	IR	NC	PS	Rank
A1	0.002888702	0.001333	0.001697	0.045523	0.025422	0.005848	0.08271	5
A2	0.086662	0.001999	0.011876	0.060698	0.102862	0.058477	0.322573	3
A3	0.173324	0.003998	0.424128	0.075872	0.205724	0.116954	1	1
A4	0.134807526	0.003332	0.016965	0.060698	0.154293	0.058477	0.428572	2
A5	0.001925824	0.000666	0.000594	0.030349	0.014695	0.003509	0.051738	6
A6	0.001925824	0.002665	0.016965	0.045523	0.073473	0.009356	0.149909	4

Table 5.73: Ranking The Alternatives For AHP Method

A	P	IP	O&M	UL	IR	NC	A*CW	Rank
A1	0.03924	0.2213	0.15365	0.07505	0.29512	0.07123	0.192011	3
A2	0.08524	0.17526	0.08221	0.15269	0.08562	0.22033	0.030565	6
A3	0.32502	0.03949	0.02037	0.44297	0.02281	0.46514	0.431919	1
A4	0.16098	0.06155	0.04083	0.17809	0.0451	0.16557	0.056007	5
A5	0.03154	0.37188	0.45468	0.02386	0.425	0.02433	0.263845	2
A6	0.35798	0.13051	0.24827	0.12733	0.12635	0.05339	0.130594	4

Table 5.74: Calculation Of The Energy İndex And Ranking The Methods

EI	α = 0.25	α = 0.5	α = 0.75	α = 0.9	Rank (α=0.25)	Rank (α =0.5)	Rank (α=0.75)	Rank (α=0.9)
VIKOR	9.340587	6.560391	3.780196	2.112078	1	1	1	1
AHP	0.120706	0.224444	0.328181	0.390424	4	4	4	4
TOPSIS	0.655997	0.705992	0.755986	0.785983	2	2	2	3
WSM	0.262726	0.508484	0.754242	0.901697	3	3	3	2

In this part four different values of α are calculated for the energy index and the results and ranking of the methods are shown in table 81.

6. RESULTS

In the previous chapter it has been shown three different parts to for solving the energy needs of Somalia mainly using four different methods to solve and rank six different alternatives. The first part, three scenarios have been introduced and for each scenario the weights of each criterion have been assigned randomly, but in close measure every time two out of the six different criterions have been given more than 50% of the entire weight. After solving for each scenario, every method is ranked by taking their first choice and calculate them by using the method sensitivity analysis, and for every scenario the choices made by the VIKOR method seemed the most appropriate ones when it comes to the capital needed to invest into those projects. Next, because weight values play an important role when it comes to MCDM methods, this time instead of using random weights, they were calculated by using one of the weight calculation methods called Standard Deviation method. Then, using those calculated weights, the methods and the sensitivity analysis of them are once again calculated. This time, the result contradicted that of the first part which VIKOR was the clear front-runner, instead the calculations made preferred TOPSIS to be the best one, but the alternative that this method chose wasn't the best one when it comes to financial matters. Facing gridlock, this time the calculations were looked from an entirely different angle. Because the original data in hand differed greatly in every alternative it has been realized that a new system was needed to ease up the massive different values in the data. A new and easy system called Per Unit system was introduced at end and with its help I managed to cut down massively the difference in the alternatives and nearly equate them with one another. Again, new weights were calculated, and the methods were once again computed and this time once again the VIKOR method choose the best one and it result was satisfying. The reason for this is the alternative that VIKOR choose, not only is it accommodating financial wise but also it is something Somalia has a great amount of and had not taken advantage of it. As mentioned in the second chapter Somalia has a great potential when it comes to renewable energy sources like solar and wind, something which it has been ranked among the most African countries in the top five, but because of its current and the previous two decades the public and private sector were either not aware of this potential or not willing to invest in.

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

In 1991 after the collapse of Somalia’s central government, that governed the country after the military revolution of October 1969, has been overthrown by violent uprising all over the country. Chaos and looting of public and private property ensued around the country and various tribal factions have gained control over their territories and started to act like mini governments themselves. The northern region of the country declared independence from the rest of the country and formed its own government and till this day are seeking recognition from the international community. Fast forward two decades later Somalia has adopted federal system and five more states have been formed and controlled by the federal government in Mogadishu.

During the chaos and looting Somalia’s, the electricity generation and distribution has been affected greatly and small and regional electricity providing companies started to distribute electricity using overhead low voltage wires. The quality of such an electricity is obviously not great and the public, those who could afford it are paying high prices for it. There are no regulations or legislations overseeing this sector, companies can charge their customers whatever they want for low quality electricity.

After two decades, in 2010 foreign governments mainly the Turkish government started to invest in Somalia mainly the capital city of Mogadishu. They overtook two main hospitals, the main airport and the main seaport, and started rebuilding some important streets in the capital. In 2014 the bank of Africa’s research in the country’s energy sector revealed some dire and some hopeful situations. Their research agreed with what is mentioned here about the energy sector that is there no effective body overseeing it and that private companies have all the power in this sector. But it has also mentioned that the EU and the WB are trying very hard to improve the situation. They have proposed several and longlasting projects that could be implemented to improve the country electricity production and distribution. The plans are merely in their infancy state because they are working hard to bring together several different actors (foreign private investors and local ones) who are willing to invest their time and money into these projects. But for any of these plans coming to fruition the EU and the WB are insisting very hard to hard the sole authority on them and, they want the regional and the federal government to provide them with any help they might need during the implementation period mainly the security and providing manpower to undertake these projects.

Multi criteria decision making techniques have been proven effective tool to deal with complicated situations that could have effects on several different issues. MCDM models have gained popularity in energy planning and management sectors because of this ability. But as good and as effective as they all are, some more than others, they have their own shortcomings when the data in hand becomes too complex or too diverse from alternative to the other. It is mainly this reason that in this thesis the data that was provided was vague and incomplete, that a new system is proposed in here. This new system cuts down on the main differences between the criterions or the alternatives and equated the data to one another to form a data that could give clear and unbiased result.

Therefore, in this thesis some of the mentioned plans have been evaluated from several different criterions like Power, Implementation Period, Operational and Maintenance cost and so on as seen in table 5. Using four different multi criteria decision making (MCDM) techniques, VIKOR, TOPSIS, WSM and AHP, these projects are computed and evaluated through their costs and the long-term effects they could have on the generation and the distribution of the electricity in Somalia. Because all the electricity generated in Somalia are done by using diesel generations which work on High Fueled Oil (HFO), this thesis reveals an alternative for such system. In the previous chapter, it has been disclosed that this alternative could come from Somalia’s natural occurring potential of renewable energy sources. Taking advantage of this naturally occurring phenomenon Somalia can enjoy cheap and clean energy from these sources.

7.2 Recommendations

The recommendations of this thesis are divided into three different parts such as recommendations to the federal and regional governments, to electricity providers and finally to foreign government or private investors.

To the Federal and Regional Governments:

The Federal Government

- Introduce and pass legislations that could set the rules and regulations for this sector.
- Provide the Ministry of Energy with the help they help it needs financially and give them authority in every region to oversee and enforce those passed legislations.
- Bring security to the main cities like Mogadishu and Kismayo so that many foreign investors whether public or private could find investing in Somalia as attractive as possible.
- Break-up big electricity providers so that the energy market could stay monopoly free and fair playground.
- Work with local businessmen to bringing in alternative to the use of charcoal as heat source.
- Cut down on the deforestation of Somalia by slowly overtime introducing ban on the use of charcoal.

To the Electricity providers

- Invest more in creating efficient electrical grid systems interconnections that could reduce the electricity lost during the transmission.
- Invest more into renewable energy sources mainly solar and wind so that dependency on HFO could be reduced.
- Invest more in the training of the personnel and technicians so that any problem within the system could be solved and managed effectively.
- Work with the federal and regions governments of the country in the security.

To foreign governments and foreign private investors

- Work with the federal and regional governments to bring security in the heavily populated cities.
- Work with the federal and regional governments to introduce and enforce energy legislations throughout the main regions.
- Work with the federal and regional governments to bring in local investors to finance and implement significant changes in energy sector.
- Keep sole authority with the local investors and exclude the government in the decision making in order to keep corruption and mismanagement out while these changes are being implemented.

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APPENDIX

Appendix1 AHP

Appendix1 AHP

The steps are the same for AHP as I have demonstrated in the Simulation chapter and following that I found this new matrix. Alternative Priority or (AP) is basically the average of each column and this results of AP in every criterion is later used to set up the new matrix for solving AHP.

Table AP 1: Pairwise comparison matrix for Power (P)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*
A1	1	0.2	0.11	0.143	2	0.11
A2	5	1	0.143	0.2	5	0.11
A3	9	7	1	5	9	0.2
A4	7	5	0.2	1	7	0.2
A5	0.5	0.2	0.11	0.143	1	0.11
A6	9	9	0.33	5	9	1
Total	***31.5***	***22.4***	***1.893***	***11.486***	***33***	***1.73***

Table AP 2: normalized decision matrix for Power (P)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*AP*	*WS*	*CV*
A1	0.031746	0.008929	0.058109	0.01245	0.060606	0.063584	0.039237	0.235423	6
A2	0.15873	0.044643	0.075541	0.017413	0.151515	0.063584	0.085238	0.511426	6
A3	0.285714	0.3125	0.528262	0.435313	0.272727	0.115607	0.325021	1.950123	6
A4	0.222222	0.223214	0.105652	0.087063	0.212121	0.115607	0.16098	0.96588	6
A5	0.015873	0.008929	0.058109	0.01245	0.030303	0.063584	0.031541	0.189247	6
A6	0.285714	0.401786	0.174326	0.435313	0.272727	0.578035	0.357983	2.147901	6

Table AP 3: consistency average, CI and CR

Average CV	*Consistency Index (CI)*	*Consistency Ratio (CR)*
6	0	0

Table AP 4: Pairwise comparison matrix Implementation period

	A1	*A2*	*A3*	*A4*	*A5*	*A6*
A1	1	2	5	3	0.5	2
A2	0.5	1	5	3	0.5	2
A3	0.2	0.2	1	0.5	0.143	0.33
A4	0.33	0.33	2	1	0.2	0.2
A5	2	2	7	5	1	5
A6	0.5	0.5	3	5	0.2	1
Total	***4.53***	***6.03***	***23***	***17.5***	***2.543***	***10.53***

Table AP 5: normalized decision matrix for Implementation Period (P)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*AP*	*WS*	*CV*
A1	0.220751	0.331675	0.217391	0.171429	0.196618	0.189934	0.2213	1.327797	6
A2	0.110375	0.165837	0.217391	0.171429	0.196618	0.189934	0.175264	1.051584	6
A3	0.04415	0.033167	0.043478	0.028571	0.056233	0.031339	0.03949	0.236939	6
A4	0.072848	0.054726	0.086957	0.057143	0.078647	0.018993	0.061552	0.369314	6
A5	0.441501	0.331675	0.304348	0.285714	0.393236	0.474834	0.371885	2.231308	6
A6	0.110375	0.082919	0.130435	0.285714	0.078647	0.094967	0.13051	0.783057	6

Table AP 6: consistency average, CI and CR

Average CV	*Consistency Index (CI)*	*Consistency Ratio (CR)*
6	0	0

Table AP 7: Pairwise comparison matrix for Operation and management cost (O&M)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*
A1	1	7	9	9	0.143	0.143
A2	0.143	1	9	5	0.11	0.11
A3	0.11	0.11	1	0.2	0.11	0.11
A4	0.11	0.2	5	1	0.11	0.11
A5	7	9	9	9	1	7
A6	7	9	9	9	0.143	1
Total	***15.363***	***26.31***	***42***	***33.2***	***1.616***	***8.473***

Table AP 8: normalized decision matrix for Operation and management cost (O&M)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*AP*	*WS*	*CV*
A1	0.065091	0.266059	0.214286	0.271084	0.08849	0.016877	0.153648	0.921887	6
A2	0.009308	0.038008	0.214286	0.150602	0.068069	0.012982	0.082209	0.493256	6
A3	0.00716	0.004181	0.02381	0.006024	0.068069	0.012982	0.020371	0.122226	6
A4	0.00716	0.007602	0.119048	0.03012	0.068069	0.012982	0.04083	0.244982	6
A5	0.45564	0.342075	0.214286	0.271084	0.618812	0.826154	0.454675	2.728051	6
A6	0.45564	0.342075	0.214286	0.271084	0.08849	0.118022	0.248266	1.489598	6

Table AP 9: consistency average, CI and CR

Average CV	*Consistency Index (CI)*	*Consistency Ratio (CR)*
6	0	0

Table AP 10: Pairwise comparison matrix for Useful Life (UL)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*
A1	1	0.2	0.143	0.2	5	2
A2	5	1	0.2	2	7	0.2
A3	7	5	1	5	9	7
A4	5	0.5	0.2	1	7	5
A5	0.2	0.143	0.11	0.143	1	0.2
A6	0.5	5	0.143	0.2	5	1
Total	***18.7***	***11.843***	***1.796***	***8.543***	***34***	***15.4***

Table AP 11: normalized decision matrix for Useful Life (UL)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*AP*	*WS*	*CV*
A1	0.053476	0.016888	0.079621	0.023411	0.147059	0.12987	0.075054	0.450325	6
A2	0.26738	0.084438	0.111359	0.23411	0.205882	0.012987	0.152693	0.916155	6
A3	0.374332	0.42219	0.556793	0.585274	0.264706	0.454545	0.442973	2.657841	6
A4	0.26738	0.042219	0.111359	0.117055	0.205882	0.324675	0.178095	1.06857	6
A5	0.010695	0.012075	0.061247	0.016739	0.029412	0.012987	0.023859	0.143155	6
A6	0.026738	0.42219	0.079621	0.023411	0.147059	0.064935	0.127326	0.763955	6

Table AP 12: consistency average, CI and CR

Average CV	*Consistency Index (CI)*	*Consistency Ratio (CR)*
6	0	0

Table AP 13: Pairwise comparison matrix for Investment Ratio (IR)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*
A1	1	7	9	9	0.5	5
A2	0.143	1	7	5	0.11	0.33
A3	0.11	0.143	1	0.2	0.11	0.143
A4	0.11	0.2	5	1	0.11	0.143
A5	2	9	9	9	1	7
A6	0.2	3	7	7	0.143	1
Total	***3.563***	***20.343***	***38***	***31.2***	***1.973***	***13.616***

Table AP 14: normalized decision matrix for Investment Ratio (IR)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*AP*	*WS*	*CV*
A1	0.280662	0.344099	0.236842	0.288462	0.253421	0.367215	0.295117	1.770701	6
A2	0.040135	0.049157	0.184211	0.160256	0.055753	0.024236	0.085625	0.513747	6
A3	0.030873	0.007029	0.026316	0.00641	0.055753	0.010502	0.022814	0.136883	6
A4	0.030873	0.009831	0.131579	0.032051	0.055753	0.010502	0.045098	0.270589	6
A5	0.561325	0.442413	0.236842	0.288462	0.506842	0.514101	0.424997	2.549984	6
A6	0.056132	0.147471	0.184211	0.224359	0.072478	0.073443	0.126349	0.758094	6

Table AP 15: consistency average, CI and CR

Average CV	*Consistency Index (CI)*	*Consistency Ratio (CR)*
6	0	0

Table AP 16: Pairwise comparison matrix for Number of Connections (NC)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*
A1	1	0.143	0.11	0.143	3	5
A2	7	1	0.2	2	9	7
A3	9	5	1	5	9	7
A4	7	0.5	0.2	1	7	5
A5	0.33	0.11	0.11	0.143	1	0.2
A6	0.2	0.143	0.143	0.2	5	1
Total	***24.53***	***6.896***	***1.763***	***8.486***	***34***	***25.2***

Table AP 17: normalized decision matrix for Number of Connections (NC)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*AP*	*WS*	*CV*
A1	0.040766	0.020737	0.062394	0.016851	0.088235	0.198413	0.071233	0.427396	6
A2	0.285365	0.145012	0.113443	0.235682	0.264706	0.277778	0.220331	1.321985	6
A3	0.366898	0.725058	0.567215	0.589206	0.264706	0.277778	0.465143	2.79086	6
A4	0.285365	0.072506	0.113443	0.117841	0.205882	0.198413	0.165575	0.99345	6
A5	0.013453	0.015951	0.062394	0.016851	0.029412	0.007937	0.024333	0.145997	6
A6	0.008153	0.020737	0.081112	0.023568	0.147059	0.039683	0.053385	0.320311	6

Table AP 18: consistency average, CI and CR

Average CV	*Consistency Index (CI)*	*Consistency Ratio (CR)*
6	0	0

RESUME

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