NEW PROPOSED INTEGRATED MCDM APPROACHES FOR THE EFFECTIVE RENEWABLE ENERGY RESOURCES SELECTION PROBLEM

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LIST OF SYMBOLS

AHP	: Analytic Hierarchy Process
ANP	: Analytic Network Process
BN	: Bayesian Network
BOCR	: Benefits, Opportunities, Costs, and Risks
BP	: British Petrol
CO_2	: Carbon Dioxide
CR	: Consistency Ratio
CSP	: Concentrated Solar Power
DEMATEL	: Decision Making Trial and Evaluation Laboratory
DM	: Decision Maker
ELECTRE	: Elimination and Choice Translating Reality English
GDM	: Group Decision Making
GHG	: Greenhouse Gas
GIS	: Geographic Information System
IEA	: International Energy
IFN	: Intuitionistic Fuzzy
IFS	: Intuitionistic Fuzzy Set
LCD	: Linguistic Consensus Degree
LOWA	: Linguistic Ordered Weighted Averaging
MACBETH	: Measuring Attractiveness by a Categorical Based Evaluation Technique
MADM	: Multi Attribute Decision Making
MCDM	: Multi Criteria Decision Making
MRV	: Monitoring Reporting and Verification
MTA	: General Directorate of Mineral Research and Exploration
MTOE	: Million Tons of Oil Equivalent
NIS	: Negative Ideal Solution
NOx	: Nitrogen Oxide
NPV	: Net Present Value
OWA	: Ordered Weight Averaging
PIS	: Positive Ideal Solution
PROMETHEE	: Preference Ranking Organization Method for Enrichment Evaluation
QFD	: Quality Function Deployment

R&D	**:** Research and Development
RER	**:** Renewable Energy Resources
TOPSIS	**:** Technique for Order Preference by Similarity to Ideal Solution
VAT	**:** Value Added Tax
VIKOR	**:** Višekriterijumsko Kompromisno Rangiranje
WC-OWA	**:** Weighted Continuous-Ordered Weighted Averaging

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ABSTRACT

The use of Renewable Energy Resources (RER) is growing rapidly for energy generation and several studies indicate that these will have a huge contribution in the future. Selecting RER is a complex problem involving different criteria and alternatives. This thesis is based on RER as a Multi Criteria Decision Making (MCDM) problem and puts forward a new evaluation model and three integrated analytic approaches to be able to select the most appropriate RER in Turkey from investor perspective.

MCDM is a powerful tool widely used to handle complex situations and assist Decision Makers (DMs) in mapping out the situations. In decision processes, Group Decision Making (GDM) combines the individual judgements of DMs in to a common opinion.

In this thesis, three approaches are presented based on Decision Making Trial and Evaluation Laboratory (DEMATEL), Analytic Network Process (ANP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The first approach is GDM based integrated DEMATEL, ANP and TOPSIS within crisp numbers. This approach involves certainty of DMs assessments in decision making process. The second proposed approach integrates GDM based integrated linguistic interval fuzzy preferences with DEMATEL, ANP and TOPSIS. This approach is useful in dealing with complex and uncertain situations. The third proposed approach includes GDM based integrated intuitionistic fuzzy (IF) DEMATEL (IF-DEMATEL), IF-ANP and IF-TOPSIS.

The originality of the thesis comes from its ability to propose effective and comprehensive a new evaluation model for both Turkey and literature and apply to RER selection problem from investor perspective. Another contribution is to adapt intuitionistic fuzzy sets (IFS) and linguistic interval fuzzy preference relations to DEMATEL, ANP and TOPSIS with GDM for the first time.

ÖZET

Enerji üretiminde Yenilenebilir Enerji Kaynaklarının (RER) kullanımı hızla büyüyor ve bu konuda yapılan araştırmalar ileride bu payın daha da artacağını göstermektedir. RER seçimi, farklı kriter ve alternatifleri içeren karmaşık bir problemdir. Bu tez RER seçimine Çok Ölçütlü Karar Verme (MCDM) problemi olarak yaklaşmakta ve Türkiye'de en uygun RER'i seçmek için yeni bir değerlendirme modeli ve üç entegre analitik yaklaşım önermektedir.

MCDM, karmaşık durumları ele almak ve durumun haritalanmasında Karar Vericilere (DM) yardımcı olmak için yaygın olarak kullanılan güçlü bir araçtır. Grup Karar Verme (GDM), bireylerin kararlarını bütün bir grup adına ortak görüş haline getirir.

Bu tezde Karar Verme Deneme ve Değerlendirme Laboratuvarı (DEMATEL), Analitik Ağ Süreci (ANP) ve İdeal Çözümle Benzerlik Üzerine Sıralama Tercihi Tekniği (TOPSIS) yaklaşımları sunulmaktadır. İlk yaklaşım, gerçek sayıları içeren GDM tabanlı entegre DEMATEL, ANP ve TOPSIS'dir. Bu yaklaşım karar vericilerin değerlendirmlerinin net olduğu durumları ele alır. İkinci yaklaşımda GDM tabanlı entegre dilsel aralıklı bulanık tercih ilişkileriyle DEMATEL, ANP ve TOPSIS önerilir. Bu yaklaşım karmaşık ve net olmayan durumlarda oldukça kullanışlıdır.Üçüncü yaklaşım GDM tabanlı entegre sezgisel bulanık (IF) DEMATEL (IF-DEMATEL), IF-ANP ve IF-TOPSIS yaklaşımlarını içerir.

Tezin orijinalliği, hem Türkiye hem de yazın için etkin ve kapsamlı yeni bir değerlendirme modeli önerilmesinden ve bunu RER seçim problemine yatırımcı bakış açısıyla uygulanmasından kaynaklanmaktadır. Bir başka katkı ise, sezgisel bulanık kümeler (IFS) ve dilsel aralıklı bulanık tercih ilişkilerini DEMATEL, ANP, TOPSIS'e ilk defa uyarlanmasıdır.

1. INTRODUCTION

Selecting appropriate Renewable Energy Resources (RER) is a mission that contains several criteria and policies. As a result of problems such as the shooting up of energy prices, awareness on global warming, climate change and dependency on depleting fossil fuels are likely to continue in the forthcoming future while global demand for energy has recently been following an increased trend. In parallel to these, the energy needs of Turkey have been increasing and becoming threat of energy shortages in next few decades. For these reasons a much affordable, clean and secure energy supply is a well-known and fundamental issue for sustainable energy resources as Turkey attempts to eliminate the dependency on depleting fossil fuels, in order to minimize the negative environmental impact and to have more economic benefits on RER.

Being the seventieth largest economy globally and sixth in Europe, Turkey experiences a pike in its energy demand, which is predicted to increase around 4-6 percent per annum until 2023. As the number of RER increases and long-term decisions regarding the selection becomes challenge for Decision Makers (DMs) to choose one particular technology among others by considering their advantages and disadvantages. Therefore, selection of RER is a strategic and crucial decision for Turkey that is bounded with many different criteria to think about.

This study presents an effective new evaluation model with Group Decision Making (GDM) based Multi Criteria Decision Making (MCDM) framework for Turkey's RER selection problem. One of the objectives of this thesis is to come up with an innovative RER selection model that consider a number of economic, environmental, social, political and technological aspects. Based on industrial experts' views and detailed literature review, a new evaluation model is obtained from the investor perspective.

Another objective of this study is to development of an integrated framework that will give the upper hand in to comparing the alternatives and then choose the most suitable one in a very effective manner. Because of proposed models' structure is a network hierarchy and able to evaluate various alternatives, Analytic Network Process (ANP) (Saaty, 1996) is utilized, which can successfully handle dependencies among decision criteria. The Decision Making Trial and Evaluation Laboratory (DEMATEL) (Gabus & Fontela, 1972) technique is to have the ability to pinpoint the mutual relationships and the magnitude of the dependencies among the decision criteria. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Chen & Hwang, 1992) is utilized to rank the RER alternatives. These MCDM methods require DMs to handle complicated situations by appraising many criteria simultaneously but differently to offer the most appropriate result. In these decision making processes, DMs may not encounter precise numbers for evaluating decision criteria, which can be as a result of DMs' bounded expertise or the subjectivity about the decision problem (Xu & Liao, 2014). To cope with this situation, fuzzy logic (Zadeh, 1965) can be employed to take the ambiguity of qualitative evaluations into account. Despite the simplicity and popularity of fuzzy based methods for handling MCDM applications, in cases when subjective human judgments need to be assessed, fuzzy sets are often criticized for not being adequate. In these cases, Intuitionistic Fuzzy Sets (IFS) (Atanassov, 1986) depict DMs evaluations with a comprehensive structure and their evaluations become more comprehensive with hesitancy. In addition, IFS present practical tools to deal with vagueness and uncertainty.

In this thesis, three approaches are presented based on DEMATEL, ANP and TOPSIS methods. The first approach is GDM based integrated DEMATEL, ANP and TOPSIS within crisp numbers. This approach involves certainty of DMs assessments in decision making process. The second proposed approach integrates GDM based integrated linguistic interval fuzzy preferences with DEMATEL, ANP and TOPSIS. This approach is useful in dealing with complex and uncertain situations. The third proposed approach includes GDM based intuitionistic fuzzy DEMATEL (IF-DEMATEL), IF-ANP and IF-TOPSIS. This approach includes IFS for reducing uncertainty and the inherent ambiguity in DMs judgments and hesitancy degree for more precise description of DMs assessments. In these approaches, GDM involves multiple experts who collaborate for reaching consensus. Here, each of the assigned DMs can voice their own opinions and may have goals that can differ from others, which affects the way they see the decision process differently. Despite individual differences in GDM, DMs have a common interest in reaching consensus for choosing the “best” alternative. The reason for GDM is that more DMs are better than a single DM in considering all significant aspects of selection problems in complex environments. Thus, GDM can often be a good option to reduce biased evaluations and the inherent partiality in decision processes (Herrera-Viedma et al., 2007).

There are eight chapters in the thesis. The first chapter gives brief information about the thesis. The second chapter introduces the definition of RER and World’s RER potential. Then, the potential of RER in Turkey and their types are examined. The literature review about RER selection and proposed RER selection approaches are given in this section. Finally, the importance of GDM based Integrated DEMATEL, ANP and TOPSIS is summarized. The third chapter presents a comprehensive literature review about utilized criteria and proposes a new evaluation model for RER selection from investor perspective. The fourth chapter of the thesis provides a detailed description of methods and presents application of RER selection by using crisp DEMATEL, ANP and TOPSIS. The fifth chapter provides a detailed description of proposed approach and presents the application of RER selection by using linguistic interval fuzzy preference relations. The sixth chapter gives a detailed description of integrated IF based approach and its application. The seventh chapter includes comparative and sensitivity analysis of utilized approaches. The last section consist of concluding remarks and future possible studies.

2. RER SELECTION

2.1 Main Concepts of RER

Energy defines as an ability to do job and a need for human beings. There are two sources of energy: renewable and nonrenewable energy. Nonrenewable energy comes from fossil fuels, such as coal, natural gas and petroleum.

As per the definition put forward by the International Energy Agency (IEA), renewable energy is the energy derived from natural events or processes such as the solar and wind activities that are replenished at a faster rate than they are consumed (IEA, 2017). On the other hand, according to the U.S. Department of Energy states explanation, renewable energy comes from energy sources that are continually replenished by nature, the sun, the wind, water, and the Earth’s heat (Amer & Daim, 2011; Gök, 2013).

Renewable Energy Resources (RER) are defined as domestic resources which have potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases (Panwar et al., 2011).

RER have been important for humans since the beginning of civilization. Clean and domestic renewable energy is commonly accepted as the key for future life and offer many environmental and economic benefits compared to traditional energy sources. In other words, each type of RER (e.g. biogas, hydro, geothermal, solar and wind energies) has its own special advantages that make it uniquely suited to certain applications in specific areas (Kahraman et al., 2009). These resources provide energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services (Sawin et al., 2016).

2.2 World's Renewable Energy Potential

Global energy scenario has been changing in rapidly during the last decades with a substantial increase in energy demand. Although energy efficiency improvements and energy savings are good options but they do not to fully resolve the issue of energy problems. Increased energy prices, awareness on global warming, climate change and dependency on depleting fossil fuels are likely to continue in the near future while global demand for energy follows an upward trend (Perez-Navarro et al., 2016). The vast majority of the world's primary energy demand is presently being met by fossil fuels, such as oil, natural gas and coal. Word total primarily energy supply in 2014 is 13699 MTOE and fossil fuels will continue to dominate the world energy mix, accounting for 80% of the world energy demand, according to projections of the IEA's World Energy Outlook.

RER is promising as a solution of environmentally friendly, low cost, secure and long-term cost effective source of energy for the future energy supply. Despite high growth rates, renewable energy still represents only a small fraction of today's global energy consumption. Today's global energy consumption is very meager even with the high growth rates. With this said and done, statistics show that the generation of electricity from renewable sources with the exclusion of hydroelectricity, is assumed to be made up of only 7% of global electricity generation. However, RER plays a very profound role in the growth of electricity whereby in 2015 it accounted for 97% of the growth in global power generation. In the same year according to a review report from BP, There was a 15,2% growth in the usage of RER for the generation of power, which fell slightly below the 10-year average growth of 15,9% but at the same time making a record increment of +213 terawatt-hours, which was more or less equal to the total amount of increment of global power generation. RER accounted for 6,7% of global power generation. The countries which recorded the highest amount of renewable energy generation were China at +20,9% and Germany at +23,5%. Globally, at +17,4% of the total wind energy growth , remains the largest source of renewable electricity where (52,2% of renewable generation), with the largest increment having been recorded by Germany by +53,4%. Solar power generation grew by 32,6%, with China, the US and Japan accounting for 69,7%, 41,8% and 58,6% respectively making them largest increases. China overtook

Germany and the US to become the world's top generator of solar energy. Global biofuels production grew by just 0,9%, which is way below the 10-year average of 14,3%: Brazil's (+6,8%) and the US's growth of 2,9% accounted for essentially all of the net increase, in converse, there were large declines in Indonesia and Argentina of 46,9% and 23,9% respectively. 2015 saw a continued growth of renewable power generation of 15%. Volume-wise in 2015, China, Germany, the US, the UK and Brazil from the largest to the least in that order, had the largest increase making them the top five biggest gainers (BP, 2015). At national level, RER are already playing an important role in some countries. With 66% of power coming from RER puts Denmark on the lead, Portugal comes next with 30%. Focusing on the bigger EU economies, RER takes a share of 27% and 24% in Germany and Spain respectively, and 23% in both Italy and the United Kingdom.

2.3 Turkey's Renewable Energy Potential

As the seventieth largest economy globally and sixth in Europe, Turkey experiences a pike in its energy demand, which is predicted to increase around 4 - 6 percent per annum until 2023 (Kaplan, 2015). On the other hand, the Turkish economy mostly depends on imported energy supply, as power generation is mainly run on fossil fuels (MFA, 2017). Almost ¾ of the total domestic energy supply of Turkey is imported and as can be seen in Figure 2.1, natural gas dominated by 37,8% of total electricity of Turkish generation in 2015. By 2023, the electricity demand by Turkey is estimated to be at 530000 GWh while the official target of this demand is to supply 160000 GWh from RER.

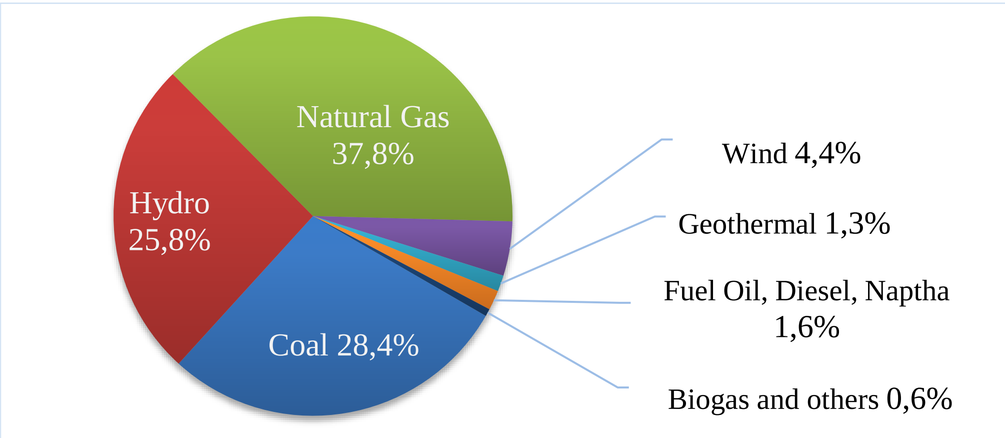

Figure 2.1: Total electricity generation of Turkey (MFA, 2017)

Putting these available data to use, it is therefore fair to say that Turkey aims to have high levels RER supplies (Institute of Energy, 2017). According to recent studies, Turkey's RER potential can be summarized in Table 2.1.

Table 2.1: Turkey's RER potential and presently used capacities (Institute of Energy, 2017)

Renewable Source	Present Brutal Potential (GWh/Year)	Technically Available Potential (GWh/Year)	Economically Considerable Potential (GWh/Year)	Used Capacity (GWh/Year)	Usage %
Hydro power	430-450	215	100-130	35,33	30
Solar	365	182*	91**	4,07	4,5
Biogas	1,58	0,79*	0,4**	0,067	16,8
Wind	400	124	98	61	62
Geothermal	16	8*	4**	0,89	22,5
* : Half of the present brutal potential value ** : Half of the technically available potential value					

The Ministry of Energy and Natural Resources statistics in 2015 indicated in Figure 2.2 that the installed power capacity of Turkey was 74000 MW of which 35,4% consisted of hydro power, followed by natural gas (28,7%), coal (21,3%), wind (6,2%), multi fueled (5,9%), geothermal (0,8%) and other sources (1,7%).

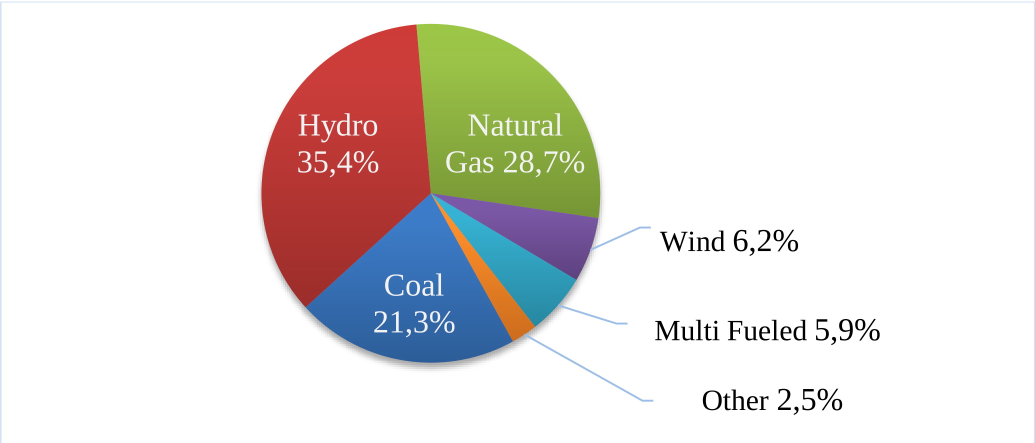

Figure 2.2: Installed power capacity of Turkey in 2015 (MFA, 2017)

All kinds of energy sources are available in Turkey, but except for lignite and hydro energy, they are not enough to meet the energy requirement of the country (Ozgur, 2008). For this reason, the country aims for low cost, clean, domestic and secure energy sources to ensure its sustainable development (Bölük & Mert, 2015). RER are emerging as a solution and be one of the important topics on Turkey's energy agenda (Kaya & Kahraman, 2010).

Turkish government has undergone significant energy reforms in last decade. One of the considerable developments that have been made in the field of RER started after the enactment of the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy in 2005. In the following years, the Turkish government created updates and implemented numerous laws and regulations, which created an enabling, forward-looking and innovative environment for RER investments. The Vision 2023 Energy Program, one of the important topics in RER program, estimates the share of RER energy production estimated as 30% (Melikoglu, 2016).

2.4 Types of RER Used in Turkey

The available RER in Turkey can be defined and summarized in the following sub sections.

2.4.1 Wind Energy

Wind energy represents the kinetic energy of wind exploited for electricity generation in wind turbines. Heat from the Sun results in the movement of winds. The potential of energy stored in the winds was recognized hundreds of years ago and was exploited mechanical machines used grinding grains, sailing ships and pumping water for irrigation purposes (Halis, 2009). Several European countries are obtaining 10% or more electricity from wind energy and this indicates that wind energy is a rapidly growing, mature and proven renewable energy technology (Amer & Daim, 2011).

Advantages of Wind Energy: Wind turbines can made technological progress to wind-rich regions. In comparison to traditional power plants, wind turbines have the capability to produce electricity at a competitive price. In reference to developing countries wind power may be catalyst to economic growth and thus offering a strong economic potential (Amer & Daim, 2011).

Disadvantages of Wind Energy: Paying more for transport, installation and maintenance of the plants makes the investment costs often higher in industrialized countries. The other disadvantage is that due to wind scarcity they do not generate any electricity. Opponents of wind farms claim that the turbines are unsightly and a danger to wildlife. It is unfortunate that the best sites for wind farms are also areas that are highly valued for their tranquility and natural beauty (Bilen et al., 2008; Halis, 2009).

Feasibility studies confirmed that Turkey has a great economic potential for wind energy production which is estimated as 50 billion kWh/year (Gök, 2013). According to wind map of Turkey (Figure 2.3) the annual amount of wind energy produced in Turkey was 7518 GWh, produced by an array of wind farms totaling 2760 MW of installed capacity (Energy and National Resources, 2017c). According to latest data of August 2016 Turkey has 347 wind power plants in operation (Institute of Energy, 2017).

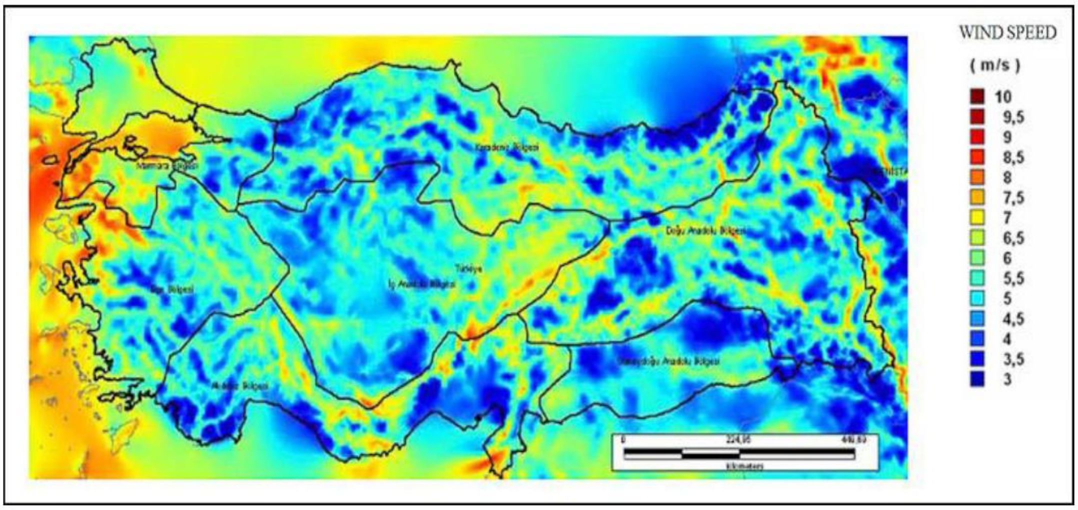

Figure 2.3: The wind map of Turkey (Gök, 2013)

2.4.2 Solar Energy

Solar energy entails the conversion of the sun’s energy into useful forms such as electricity or heat. There are quite number of factors that do specify the amount of solar radiation received at a specific location, they include geographic location, time of day, season, local landscape, and local weather (Amer & Daim, 2011).

There are two ways in which soar energy can be converted into electricity (Energy and National Resources, 2017b). First one is Photovoltaic or solar cells, which have a system to change sunlight directly into electricity. They are the most common type of solar energy generation and can be seen on wristwatches, calculators, and on the roofs of buildings. The second one is Concentrated Solar Power Plants (CSP) which generates electricity by using the heat from solar thermal collectors to heat the fluid which produces steam (Kayakutlu & Mercier-Laurent, 2017). In contrast with the PV cells, the CSP plant first generates heat, so it can store the heat before conversion to electricity. Taking advantage of current technology, storage of heat is much cheaper and more efficient than storage of electricity. As a result, the CSP plant has the capacity to produce electricity day and night uninterruptedly (Amer & Daim, 2011).

Advantages of Solar Energy: The advantage of PV is to convert solar to electricity without turning any part. CSP are simple and can be very cheap to introduce, especially the passive systems.

Disadvantages of Solar Energy: The disadvantages of PV are: high capital cost, high land use, low conversion efficiency. Dependent to the sun so availability factor is low. The disadvantages of CSP can be presented as; Solar power is less harnessed or rather not common in regions with higher altitude like Turkey due to frequent cloud and the variations in solar radiations due to seasonal changes (Halis, 2009).

Having a high potential for solar energy due to its geographical position as seen in Figure 2.4, Turkey has high solar energy potential with its annual insolation time of 2737 hours, which corresponds to a total of 7,5 hours per day. This translates into a total solar energy of 1527 kWh/m^2 per year (total 4,2 kWh/m^2 per day) on average (Energy and National Resources, 2017b).

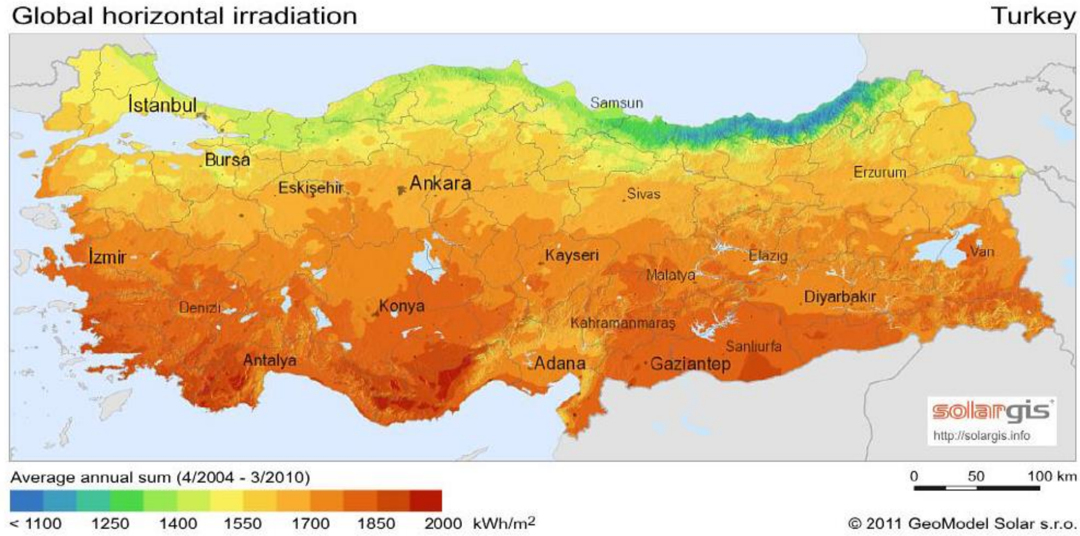

Figure 2.4: The solar map of Turkey (Energy and National Resources, 2017b)

2.4.3 Biogas Energy

Biomass can be defined as the organic material obtained from (recently) living species. It is basically atmospheric carbon bound in organic matter by photosynthesis at a stage of the ecologic chain. Biomass can be farmed sustainably, which can be observed in biodiesel, biogas, and bio-ethanol production. In this study, biogas and landfill gas are considered for the case study. Biogas is a promising technology, as it can at the same time increase electricity production, generate by-products that can be used as fertilizer, and also reduce organic waste generated in agriculture, forestry, communities and other residues of organic matter (Perna, et al., 2016). Common biomass sources (including traditional and modern biomass) can be exemplified as, agricultural crops, forestry crops, animals and industrial residues, sewage and municipal solid wastes.

Advantages of Biogas Energy: In comparison to other type of fuels, Biomass has a tendency to be low cost and shows neutrality on carbon. The demand for the earth's resources is reduced with an increase use of biomass. The other advantage biomass has over fossil fuels is simply that releases no more CO2 than the plants have previously absorbed from the air (Bilen et al., 2008).

Disadvantages of Biogas Energy: Greenhouse gases and particulates are released through burning. In addition, collecting biomass materials in sufficient quantities may prove difficult. Capital and operation cost is high because of new technology, also a few experts exist to install all system (Halis, 2009).

Biogas is a promising technology for Turkey, as it can at the same time increase electricity production, generate by-products that can be used as fertilizer, and also reduce organic waste generated in agriculture, forestry, communities and other residues of organic matter (Perna et al., 2016). When biodiesel is considered for the case of Turkey, the installed biodiesel capacity of 160 thousand tons is dwarfed by the total fossil fuel consumption of 22 million tons, 3 million tons of this being petrol. According to latest data of August 2016 Turkey has 28 Biomass plants (Institute of Energy, 2017).

2.4.4 Hydro Energy

Hydro energy is the only renewable energy source that can already boast a substantial share of today's electricity generation. Hydroelectric power stations exploit the huge gravitational (potential) energy that is contained in rivers in mountainous regions (Halis, 2009).

Advantages of Hydro Energy: The energy source is constant, making it more reliable than other renewable. Water can be stored up when energy demand is low and used when demands increase. Hydroelectric plants also boast of flexibility, that is, they are able to shut on and off, depending on the load in the power grid, as they can reach peak output faster than other power stations.

Disadvantages of Hydro Energy: Suitable sites for dams are rare and hydroelectric plants are very expensive to build. When a new power plant construction project conceived, the issue of sustainability should be looked into very carefully, because the construction of new plants especially of very large dams strongly damaging to the environment (Kayakutlu & Mercier-Laurent, 2017).

Turkey has ambitious hydropower plans over the coming decade. The country aims at marking its 100 years as a republic in 2023 with a total installed electric power capacity of 100 GW – up from 32 GW in 2002 and 64 GW in 2014 – with 30 per cent of electricity generation coming from renewables. This rate was around 20 per cent in 2014 due to low rainfall. The country is pushing ahead with its formidable goal to exploit all of its estimated 166000 GWh/year of economical hydropower potential, which would include an expected total of about 24000 hydropower plants. To date, roughly 50 per cent of this potential has been tapped, with a further 15 per cent under construction, leaving the country with some way to go in achieving its target. At the end of 2014, Turkey's installed hydropower capacity was 23,6 GW, producing 40400 GWh/year of electricity (IHA, 2017).

Turkey has a suite of policies that will support hydropower development, including a 30 per cent target for renewables by 2023, a feed-in-tariff for projects completed by the end of 2015, VAT and customs exemptions, and license fee exemptions for renewable projects.

2.4.5 Geothermal Energy

Geothermal Energy is the heat energy obtained from hot water, steam and dry steam, and hot dry rocks, which is formed when heat accumulated in deep subterranean rocks is carried by fluids and stored in reservoirs. Geothermal resources are mainly found around active fault systems and volcanic and magmatic units (Energy and National Resources, 2017a).

Advantages of Geothermal Energy: It is seen that very little visual impact on the environment. It has low land use and high thermal efficiency.

Disadvantages of Geothermal Energy: It is difficult to find suitable sites for geothermal schemes, which are hard, for example, the rocks need to be drilled through easily, and the hot rocks also need to be close enough to the surface to be easily reached. Also, some hazardous gases may come up from the rocks, and their handling and disposal may be a problem, and some geothermal site have been known to “run out of steam” for long periods so re-injection must be operated (Halis, 2009).

Turkey has a high geothermal potential and ranks 7th globally and 1st in Europe. The total installed capacity of geothermal facilities in Turkey as of 2013 is 11766 MW(Energy and National Resources, 2017a) and total capacity has increased dramatically in recent years. According to latest data of August 2016 Turkey has 34 geothermal plants (Institute of Energy, 2017) and Turkey targets geothermal electricity production amount has been announced as 1500 MWe for 2023.

Between 2010 and 2015, a total of about 320 geothermal exploration, production and injection wells for electricity production and direct use purposes have been drilled in Turkey with a total depth of total 570 km drilled by MTA and the private sector in Turkey. Nearly 80% of the geothermal exploration wells have been drilled in the Western Anatolia in Turkey.

2.5 Literature Review of Effective RER Selection

Globally, energy generation finds an alternative in RER are and various researches point out that these resources will have vital importance in the future. To have sustainable development, Limited reserves and negative environmental impacts of fossil fuels make investors to consider RER. As the number of RER alternatives increase, it becomes more difficult for DMs to take long term decisions to choose one particular alternative among others by considering all their advantages and disadvantages. Therefore, the selection of RER is a strategic and crucial decision for a country with many different criteria to think about. As it is emphasized in Table 2.2 (Table divided to four pieces through pages) researchers stressed out the importance of RER covering last 10 years studies.

Table 2.2a: Several studies in RER selection

Year	Author(s)	Aim of the study	Analysis techniques	Country	Selected alternatives	Type
2007	Gökçek et al.	To investigate the wind energy potential in Marmara region	Weibull Distribution	Turkey	Wind	Case study
2008	Patlitzianas et al.	To establish a new energy system for firms	MCDM, Decision Support Systems	Ten new European countries	-	Case study

Table 2.2b: Several studies in RER selection

Year	Author(s)	Aim of the study	Analysis techniques	Country	Selected alternatives	Type
2007	Gökçek et al.	To investigate the wind energy potential in Marmara region	Weibull Distribution	Turkey	Wind	Case study
2008	Patlitzianas et al.	To establish a new energy system for firms	MCDM, Decision Support Systems	Ten new European countries	-	Case study
2009	Kahraman et al.	To determine the most appropriate renewable energy alternative	Fuzzy AHP, Fuzzy Axiomatic Design	Turkey	Wind	Case study
2010	Cinar et al.	To provide a general overview for energy policies	Causal Maps, Bayesian Networks	Turkey	Hydro	Case study
2010	Kahraman & Kaya	To determine the best energy policy	Fuzzy AHP	Turkey	Wind	Case study
2010	Kaya & Kahraman	To determine the best renewable energy alternative for Istanbul	VIKOR AHP	Turkey	Wind	Case study
2010	Kahraman et al.	To select RER based on computing with words	Choquet Integral	Turkey	Wind	Illustrative example
2011	San Cristobal	To select a renewable energy investment project	VIKOR AHP	Spain	Biomass	Case study
2011	Kaya & Kahraman	To select the best energy technology alternative	AHP, TOPSIS and Fuzzy Logic	Turkey	Wind	Case study
2012	Erol & Kılkış	To select energy policy for sustainable energy	AHP	Turkey	Solar	Case study
2012	Baris & Kucukali	To explore the availability and potential of RER	MCDM Analysis Tool	Turkey	Biomass	Case study
2012	Iskin et al.	To provide RER pricing	ANP	Turkey	-	Case study
2012	Sadeghi et al.	To determine the best RER for generating electricity	Fuzzy AHP, Fuzzy TOPSIS	Iran	Solar	Case study
2012	Boran et al.	To evaluate RER for electricity generation	IF- TOPSIS	Turkey	Hydro	Case study
2012	Boran et al.	To evaluate energy policy based on an information axiom	Axiomatic Design	Turkey	Hydro	-
2013	Ertay et al.	To select best RER for sustainable development	MACBETH, AHP	Turkey	Wind	Case study
2013	Gök	To prioritize development of RER	AHP	Turkey	Hydro	Case study

Table 2.2c: Several studies in RER selection

Year	Author(s)	Aim of the study	Analysis techniques	Country	Selected alternatives	Type
2013	Demirtas	To determine the best RER technology for sustainable energy planning	AHP	Turkey	Biomass	Case study
2013	Sánchez-Lozano et al.	To obtain the evaluation of the optimal placement of photovoltaic solar power plants	GIS, TOPSIS AHP	Spain	Solar	Case study
2013	Stein	To rank RER alternatives	AHP	USA	Wind/Solar	Case study
2014	Kabak & Dağdeviren	To prioritize RER alternative	ANP, BOCR	Turkey	Hydro	Case study
2014	Büyüközkan & Güleryüz	To develop a new model for the selection of RER	Fuzzy AHP, Linguistic Interval Fuzzy Preferences, Fuzzy TOPSIS	Turkey	Wind	Case study
2015	Erdogan & Kaya	To select energy alternatives	Type 2 Fuzzy AHP, Type 2 Fuzzy TOPSIS	Turkey	Wind	Case study
2015	Bölük & Mert	To examine the potential of RER in reducing the impact emissions	Kuznets Curve	Turkey	Hydro	Case study
2015	Franco et al.	To select suitable location for biomass plant	GIS	Denmark	Biogas	Case study
2015	Kuleli Pak et al.	To determine a renewable energy perspective	ANP, TOPSIS	Turkey	Hydro	Case study
2015	Şengül et al.	To develop MCDM framework for ranking RER	Fuzzy TOPSIS, Interval Shannon's Entropy	Turkey	Hydro	Case study
2015	Onar et al.	To select wind energy technology	Interval-valued Intuitionistic Fuzzy Sets, AHP	Turkey	Wind	Case study
2015	Öztaysi & Kahraman	To select RER alternatives	Type-2 Fuzzy AHP, Hesitant TOPSIS	Turkey	Wind	Case study
2016	Büyüközkan & Güleryüz	To select RER alternatives	DEMATEL, ANP	Turkey	Wind	Case study
2016	Çelikbilek & Tüysüz	To select RER alternatives	DEMATEL, ANP, VIKOR, Grey Values	Turkey	Solar	Case study
2016	Cebi et al.	To select suitable location for biomass plant	GIS	Turkey	Biomass	Case study

Table 2.2d: Several studies in RER selection

Year	Author(s)	Aim of the study	Analysis techniques	Country	Selected alternatives	Type
2016	Kayal & Chanda	To determine location of RER plants	Optimization with a Stochastic Search Technique	-	-	Case study
2017	Kuleli Pak et al.	To determine best energy policy	ANP	Turkey	Hydro	Case study
2017	Mousavi et al.	To select best renewable energy policy selection	ELECTRE	Iran	Solar & Hydro	Case study

In literature, RER is an important subject that attracts notable amount of articles and research papers. According to several authors, RER has recently been following an increased trend in RER selection, evaluation and energy policy related subjects. Since RER evaluation contains many conflicting criteria to be considered, it becomes more difficult for DMs to identify an alternative that maximizes all decision criteria (Kaya & Kahraman, 2010). Putting this difficulty into consideration, MCDM methods are quite useful in undertaking difficult assessment procedures.

From the online journals and National Thesis Center of Turkey, Table 2.2 is formed. It is seen that some studies focus on different techniques such as kuznet kurves, optimization techniques and stochastic methods. However, MCDM (such as Analytic Hierarchy Process – AHP, TOPSIS, ELECTRE, VIKOR) are used in several studies both in scientific journals and publications in the area of RER evaluation and selection problem. As these studies demonstrate, MCDM can provide a technical and scientific decision making support tool that is able to justify its choices clearly and consistently, especially in the renewable energy sector.

2.6 Proposed Methodology for Effective RER Selection

2.6.1 GDM Based Integrated DEMATEL, ANP and TOPSIS

GDM problem may be defined as a decision problem with several alternatives and a panel of DMs or experts that try to achieve a common solution taking into account their opinions or preferences (Tapia Garcia et al., 2012). The resolution method for a GDM problem is composed by two different processes: First one is consensus process which refers to how to obtain the maximum degree of consensus or agreement among the experts on the alternatives of the solution. Second one is the selection process which consists of how to obtain the solution set of alternatives from the opinions on the alternatives given by the experts.

In many practical situations, particularly in the process of GDM, the DMs may come from different research areas and thus have different ways of thinking and levels of knowledge, skills, experience, and personality. When DMs may not have enough expertise or possess a sufficient level of knowledge to precisely express their preferences over the criteria, these challenges can be solved with the use of GDM considering a common interest to reach collective decision (Büyüközkan & Güleryüz, 2014).

One of the most commonly used methods to deal with high uncertainty, clashing objectives with various interests and multiple perspectives is the use of MCDM. There are some discussions in the literature about the "right" method applied to a real-life problem. MCDM refers to the process of finding the "best fitting" solution where many different decision criteria are to be taken into account simultaneously. Generally, MCDM techniques include four essential steps that support the making of more efficient, rational decisions. Firstly, the decision process, alternative selection and criteria formulation is structured. Secondly, tradeoffs among criteria and criteria weights are determined. Thirdly, value judgments concerning acceptable tradeoffs and evaluation are applied. Finally results are evaluated and decisions are made (Abu-Taha, 2011).

MCDM contain several different methods, the most common of which are the AHP, ANP, PROMETHEE, ELECTRE, TOPSIS etc. As one of the many different MCDM methods, ANP introduced by (Saaty, 1996) is frequently used, which is basically the extension of the well-known AHP (Saaty, 1980). ANP is capable to deal with complexities by incorporating interdependencies and feedback of among criteria and alternatives in decision model ANP differs from AHP in that it allows feedback and interdependence among criteria. Therefore, ANP is its ability to handle the problems that cannot be modeled as a hierarchy and to make predictions more accurate with better priority calculations in cases of networks with dependent criteria (Saaty, 1996).

The ANP approach has major advantages: Firstly, by using ANP, the criteria priorities can be determined based on pair wise comparisons by DMs evaluation, rather than arbitrary scales; secondly, DMs can consider both tangible and intangible factors; thirdly, ANP can transform qualitative values into numerical values for comparative analysis; the fourth one is being simple and intuitive approach that DMs can easily understand and apply it without specialized knowledge; the fifth one is to allows participation of all DMs in the decision making process (Kabak & Dağdeviren, 2014). Therefore, ANP has flexible network structure and the elements of the ANP system may interact themselves.

In Turkish energy sector, ANP is used to solve different kinds of decision making problems, such as Ulutaş (2005) for the determination of the appropriate energy policy for Turkey, Erdoğmuş et al. (2006) for evaluating alternative fuels for residential heating, and Köne & Büke (2007) for evaluating alternative fuels for electricity production. Iskin et al. (2012) for exploring the RER pricing, Büyüközkan & Güleryüz (2014) for selecting the most suitable energy alternative for Turkey, Kuleli Pak et al. (2015) for determining RER perspective.

In complex decision making problems, many elements can be related with each other directly or indirectly. In these situations, it becomes a challenge for a DM to avoid all other factors and to formulate an isolated evaluation between a single effect and a single factor (Chen & Chen, 2010). Moreover, strictly assuming a hierarchical structure which gives rise to linear activity with no dependence or feedback can cause problems that are different than the ones in non-hierarchical systems (Tzeng et al., 2007). To deal with these, DEMATEL method (Gabus & Fontela, 1972) can be used. DEMATEL can effectively build the structure of a relationships map with clear interrelations among sub-criteria for each criterion. It can also be applied to establish causal diagrams that are able to visualize the causal relationship of sub-systems (Büyüközkan & Çifçi, 2011). According to Gabus and Fontela (1972), DEMATEL can be utilized for measuring qualitative and factor-related aspects that are frequently faced in societal problems, as well as challenging problems that involve interactive man-model techniques. In literature, industrial planning, decision making, regional environmental assessment, sustainable development and other world problems are different topics that DEMATEL is adapted for (Rahman & Subramanian, 2012).

In recent years, many researchers recently have been interested in comparing two or more MCDM methodologies and summarize the advantages of each method. This proposed combined method has a profound and paramount advantage in that it is a flexible and robust way for DMs to better come to terms to a decision problem in case of uncertainty and lack of clarity in DMs perceptions. Another advantage is that with this method a collective decision is achieved by combining DMs' assignments in appropriate ways, based on a satisfactory degree of agreement by using GDM consistent with human thoughts.

DEMATEL and ANP techniques are incorporated to determine the degree of dependencies among criteria and use these degrees to normalize the unweighted supermatrix in ANP. Recently, Gölcük and Baykasoğlu (2016) and Büyüközkan and Güleryüz (2016b) analyzed combined DEMATEL and ANP approaches and clearly highlighted why DEMATEL based ANP has some further theoretical and practical characteristics that make it favorable to the traditional ANP. These qualities are briefly exposed in the following items (Büyüközkan & Güleryüz, 2016b):

Identification of criteria structure: The criteria structure must be known before applying ANP. Despite its strong mathematical foundations, ANP does not put into any systematic approach to identify criteria and associated clusters, and their inner dependencies. With this fundamental reason in to play therefore, DEMATEL is widely used to bring to comprehension the network relationship map of the problem in the literature.

Pair-wise comparisons and survey questions: In general, pairwise comparisons are cognitively demanding. Moreover, identification of the priorities for inner dependencies necessitates some ambiguous questions that need answers. To overcome this difficulty, inner dependency related priorities in the supermatrix are calculated by DEMATEL.

Given the fact that the DEMATEL method is mainly focused on the cause-effect type of relationships, it is therefore more practical to construct a direct relation matrix.

Unequal importance of clusters: In traditional ANP, clusters of criteria are assumed to be equally important. As this cannot always be true in general, influences among clusters can be obtained with DEMATEL. Moreover, influence degrees among clusters can be used to weight the unweighted supermatrix, which results to weighted supermatrix. All columns of the weighted supermatrix are sum to unity so that it can be raised to large powers to obtain steady state weights.

TOPSIS is one of the best known MCDM methods, which was initially proposed by Chen & Hwang (1992) and developed by Hwang and Yoon (1981) is based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution, and the longest distance from the negative ideal solution. The positive ideal solution is the solution which maximizes the benefit criteria as well as minimizes the cost criteria, also the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Kannan et al., 2014). TOPSIS is all about a simple computation process which implores a systematic procedure, and also the application of sound logic that puts the rationale of human choice in to consideration. TOPSIS is advantageous as only limited amount of subjective input is needed from DMs. Also it is able to rank the best alternative quickly (Vinodh et al., 2014).

2.6.2 Summary of Utilized and Proposed Approaches

In this thesis, integrated DEMATEL, ANP and TOPSIS approach is selected as a systematic analytic model to determine the most appropriate RER alternative for Turkey. The applied techniques in selection process are summarized as:

- GDM Based integrated DEMATEL, ANP and TOPSIS.
- GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS.
- GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS.

The first approach is GDM based integrated DEMATEL, ANP and TOPSIS within crisp numbers. In this technique, DMs assessments are given in crisp numbers which shows that DMs assessments are in certain environment.

The second proposed approach integrates GDM based linguistic interval fuzzy preferences with MCDM. It is a useful technique in dealing with highly complex and uncertain situations. GDM is a useful approach to form a model of the decision process, especially in circumstances when DMs' differing opinions are needed to end up with group preferences (Herrera-Viedma et al., 2007).

The third proposed approach is based on GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS. This approach includes IFS for reducing uncertainty and the inherent ambiguity in DMs judgments. Instead of precise numerical values, both the membership and the non-membership and hesitancy degrees are involved in an IF environment.

It should be pointed out that applying only one of the techniques would already have been satisfactory in an MCDM problem. However, by integrating these three techniques in combination, the procedure is improved in terms of efficiency and effectiveness. According to surveyed literature, it is believed that there has been no studies that considers DEMATEL, ANP and TOPSIS integrated methodologies in energy sector and this is one of the contributions of our thesis. The other originality of the thesis comes from the proposition of GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS for the first time in literature. The proposed GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS provide support in dealing with complex problems and IFS include hesitation degree to depict DMs assessments in a more accurate and extended way. As it will be mentioned in the following sections, there is no evidence in the literature that proposed GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS are applied to the literature. Hence, this is the other contribution of the thesis.

3. MODEL DEVELOPMENT FOR EFFECTIVE RER SELECTION

3.1 Identification of Evaluation Criteria

As one of the most attractive topics in modern energy, RER has been investigated by many researchers, academicians, private, and public sector. Benefits, barriers, and supporting policies associated with different types of renewable energy sources are among main research topics. There are many studies conducted for identifying the development of which RER should be given priorities in the world. Some of these studies are given below by considering technical, economic, political, social and environmental aspects on the evaluation of RER. On top of these aspects, discussions with DMs can provide some improvements during the decision process. From an investor's perspective, DMs may encounter difficulties in selecting the most suitable alternative among many RER alternatives. During the construction of the decision model, the selection criteria are unquestionably one of the most fundamental parts. With this in mind, clearly defined criteria are important for the alternatives to be compared from a specific point of view.

Model development is one of the main objectives in the thesis. There can be many models to choose the most appropriate RER alternative. Based on a detailed literature survey and the contribution of industrial experts, this study attempts to develop an appropriate model for selecting RER. More detail way, information gathered from industrial experts, laws on utilization of RER, several published investment project reports, conference papers, news and web links of General Directorate of Renewable Energy, Ministry of Energy and universities and many similar organization's web sites.

In evaluating RER, the main criteria consist of Technical, Economic, Political, Social and Environmental Aspects. The definitions of all criteria are provided in the following sections.

3.1.1 Technical Aspects

Technical Aspects include Efficiency, Reliability, Resource Availability, Installed Capacity and Technology Maturity / Innovation.

- **Efficiency**

The quantity of useful energy that can be obtained from an energy resource is known as efficiency. The efficiency coefficient is the ratio of the output energy to the input energy, which is used to evaluate energy systems. Energy efficiency is considered to be one of the ‘‘twin pillars’’ of a sustainable energy policy. Efficient energy use is paramount requirement to slow down the energy demand growth. It stands out as the most preferred technical criteria to evaluate energy systems (Amer & Daim, 2011; Atmaca & Basar, 2012; Kaya & Kahraman, 2010; Talinli et al., 2010; Wang et al, 2009).

- **Reliability**

The capability of a system to show performance under defined or intended guidelines or conditions is known as Reliability. Also, it evaluates the technology of the renewable energy (Kahraman et al., 2010; Wang et al., 2009). Reliability is often closely related with equipment quality, operation and maintenance, fuel type and the design of the energy system. Reliability of energy systems is amongst the most important criteria for the evaluation of RER (Wang et al., 2009).

- **Resource Availability**

Resource availability refers the existence of RER components or reserves that is wind, speed, solar radiations etc. to generate energy. Alternatively, the security for the possibility of the implementation of renewable energy is being weighed by this criteria. The alternative having the availability of more resources is considered a better one (Amer & Daim, 2011; Aras et al., 2004; Chatzimouratidis & Pilavachi, 2009; Fetanat & Khorasaninejad, 2015).

- **Installed Capacity**

Capacity of the investment variable refers to the role of investment capacity in terms of electricity generation capacity or investment amount in energy related decision making practices (Iskin et al., 2012). The role of technology related parameters such as geographical characteristics and production technology (Bürer & Wüstenhagen, 2009; Chatzimouratidis & Pilavachi, 2009; Amer & Daim, 2011; Iskin et al., 2012; Yeh & Huang, 2014). Impact of these variables in capacity investment will be presented in the variables; production technology and geographic characteristics.

- **Technology Maturity / Innovation**

Technology maturity is indicated by a specific technology's penetration in the energy mix at regional, national and international levels (Chatzimouratidis & Pilavachi, 2009; Amer & Daim, 2011). Technology maturity is a useful parameter in investment decisions, as it affects many parameters, such as the speed of implementation, understanding and familiarity of investors and policy makers about the efficiency, reliability and cost effectiveness of RER and decides accordingly. Considering that there are different energy technologies that are developed more recently, technological maturity should be taken into account when deciding on the financial aspects in the long term (Iskin et al., 2012).

3.1.2 Economic Aspects

Economic Aspects consist of Investment Cost, Operation and Maintenance Cost, Technology and Know-How Cost, Return on Investment and Revenue and Financial Structure.

- **Investment Cost**

Investment cost refers to the overall expenditures incurred during the establishment of the energy technology alternative including labor, purchase of mechanic equipment, technological installation, infrastructure, engineering services and other incidental construction work. Investors frequently use this economic parameter in their decisions when they compare energy systems (Cavallaro & Ciraolo, 2005; Erdoğmuş et al., 2006; Bürer & Wüstenhagen, 2009; Chatzimouratidis & Pilavachi, 2009; Kaya & Kahraman, 2010; Amer & Daim, 2011; Atmaca & Basar, 2012; Fetanat & Khorasaninejad, 2015; Yeh & Huang, 2014).

- **Operation and Maintenance Cost**

Operation and maintenance refer to running expenses of RER and is thus made up of two divisions. One of these divisions, is the operation cost that includes employees' wages, and the funds spent for the energy, the products and services for the energy system operation. The other one is the maintenance cost that aims to prolong energy system life and avoid failures that may lead to its operation suspension. The funds spent for maintenance are less than the financial damage obtained from an energy system failure and the credibility and confidence index of the energy system increases. Proper maintenance is necessary to ensure reliable and continuous operation in confidence for any energy system. In other words, operation and maintenance costs include all production costs that are associated with running a power plant. Operation and maintenance cost includes production costs associated with regulation of existing power plants. (Cavallaro & Ciraolo, 2005; Erdoğmuş et al., 2006; Önüt et al, 2008; Chatzimouratidis & Pilavachi, 2009; Wang et al., 2009; Talinli et al., 2010; Kaya & Kahraman 2010; Atmaca & Basar, 2012; Iskin et al., 2012; Yeh & Huang, 2014).

- **Technology and Know-How Cost**

This criterion comprises expenses which occur on the research and development of technological innovations (Nigim et al., 2004; Amer & Daim, 2011). Based on DMs propositions technology and know-how cost is presented.

- **Return on Investment**

Return on investment refers to the number of years that cost of using an asset stays financially optimal. This criteria judges the proposed renewable energy alternative economically and considers the project's worth on its investment. Return on investment refers to significance of economic life considerations in energy related decision making practices. This criteria is widely applied in economic assessment of energy alternatives in the literature and can be therefore measured by NPV or payback period methods (Nigim et al., 2004; Wang et al., 2009; Iskin et al., 2012).

- **Revenue and Financial Structure**

This criteria pay attention to the availability of loans, debt/equity ratio, cost of debt that affects the value of a business. Based on DMs propositions Revenue and Financial Structure criteria is presented.

3.1.3 Political Aspects

Political Aspects includes Foreign Dependency, Compatibility with Legal Compliance, Compatibility with National Energy Policy Objectives and Legal Incentives.

- **Foreign Dependency**

Foreign dependency analyzes the integration of national energy policies with renewable energy alternatives and considers the dependency of countries to international legislations (Goletsis, Psarras, & Samouilidis, 2003; Erdoğmuş et al., 2006; Önüt et al, 2008; Iskin et al., 2012). RER can benefit from government-supported schemes and other international incentives, such as tax exemptions, compensations, feed-in tariffs, simpler regulations and promotions.

- **Compatibility with Legal Compliance**

This criterion includes political aspects, compares the suggested policy's consistency with the governmental policies. Decisions regarding energy investments are closely related with national legislation incentives or force investors to comply with certain energy goals. An example can be portfolio standards for power suppliers that force them to source a certain amount of their energy from RER. This criterion measures the existence and enforcement of RER-supportive legislation (Kahraman & Kaya, 2010; Yeh & Huang, 2014).

- **Compatibility with National Energy Policy Objectives**

This criterion consists of the national energy policy related with RER. To improve the international competitiveness and technological development, specific government policies may need to be adopted, such as grants and subsidies, assistance in establishing a complete supply chain, and aid for carrying out R&D activities (Talinli et al., 2010; Kahraman et al., 2010; Amer & Daim, 2011; Iskin et al., 2012; Yeh & Huang, 2014).

- **Legal Incentives**

This criterion incorporates public incentives and financial accessibility by utilizing RER. Regional or national regulations can affect investment decisions in a preventive or supportive manner. This criterion measures the impact of energy policies on the decisions of investors, such as the installed capacity for energy projects, fund allocation and the generation technology selection (Bürer & Wüstenhagen, 2009; Iskin et al., 2012; Yeh & Huang, 2014).

3.1.4 Social Aspects

Social Aspects involve Social Benefits, Social Acceptability and Job Creation.

- **Social Benefits**

During the development of RER, Social benefits, which entails public opinion, is a key element. This criterion encompasses all benefits of RER, for instance a social life and income generation that would prevent people from emigrating from rural lands for public welfare. It expresses the local social progress that is linked with the introduction of a RER project, in particular when located in a less developed region. Social benefits can be assessed qualitatively, as the level of success cannot be measured in absolute terms. Although highly recapitulative, proxy measures such as the number of new jobs, social life aspects and local income generation can be used in evaluating this criterion. Social benefits are frequently taken into account in sustainable energy considerations (Erdoğmuş et al., 2006; Önüt et al., 2008; Wang et al., 2009; Amer & Daim, 2011; Atmaca & Basar, 2012; Iskin et al., 2012).

- **Social Acceptability**

Social acceptability is defined as people's approval and affirmative opinion on RER (Goletsis et al., 2003; Cavallaro & Ciraolo, 2005; Wang et al., 2009; Kahraman & Kaya, 2010; Amer & Daim, 2011; Iskin et al., 2012). It is a measure used for aggregating the opinions of local stakeholders related to energy systems by comparing the current situation with the hypothetical project realization scenario. The overall opinion of local populations and of pressure groups can heavily influence the progress with investment decisions. Similarly, social acceptance is not expressed in quantitative terms, but can be assessed qualitatively, for instance based on surveys carried out locally (Wang et al., 2009; Kahraman & Kaya, 2010).

- **Job Creation**

Job creation corresponds to direct and indirect employment, as well as creation of new professional areas indirectly (Erdoğmuş et al., 2006; Wang et al., 2009; Amer & Daim, 2011; Iskin et al., 2012). Those sustainable energy systems that can create a relatively larger number of local and qualified jobs will be more beneficial as they will be able to substantially improve the living quality of local people. Local governments prioritize job creation as an objective of energy systems and prefer projects with more employment opportunities to others. RER investments are able to mobilize highly qualified people, including engineers, field personnel and office workers. Nevertheless, the number and quality of jobs will largely depend on parameters like the technology, installed capacity and geographic location. Noting the wide range of job categories, many of which can be project-specific, comparison of employment opportunities can be facilitated by assigning job profiles into one of the following three major categories; i.e. direct jobs, indirect jobs and induced jobs. Direct jobs represent new employment that is directly created by the project owners as a result of construction, manufacturing and operation activities for the project under investigation. Indirect jobs involve additional employment resulting from procurement of goods and services from third parties for plant construction and operation. These can be service providers for maintenance and repair, as well as suppliers. Induced jobs can be attributed to a project more remotely and are created due to an evolving local economy and industrial expansion (Wang et al., 2009; Iskin et al., 2012).

3.1.5 Environmental Aspects

Environmental Aspects consist of Greenhouse Emissions, Land Use / Requirement and Impact on Ecosystem.

- **Greenhouse Emissions**

Greenhouse gases such as CO2, NOx etc. that mainly contribute to global warming, and some of them also lead to air pollution and acid rains (Cavallaro & Ciraolo, 2005;Önüt et al., 2008; Wang et al., 2009; Talinli et al., 2010; Kahraman & Kaya, 2010; Amer & Daim, 2011; Kaya & Kahraman, 2011). Greenhouse gas concentrations in the air directly affect public health and indirectly affect the social welfare of the community. CO2 major greenhouse gas is mainly released through burning of fossil fuels. Although CO2 can be captured and stored back by plants by photosynthesis, global deforestation trends prevent effective removal of atmospheric CO2. Power generated with gas, coal and oil does not only produce a high amount of carbon dioxide, but also NO_x, another greenhouse gas, in particular when the combustion takes place at higher temperatures. These emissions lead to climate change, which threatens social structures in various dimensions (Wang et al., 2009).

- **Land Use / Requirement**

Land use / requirement states that energy systems need space in order to generate energy where for energy investments cause strong demand for suitable land. Energy systems inevitably affect the environment and landscape they are built in. These impacts can be amplified for cases where nearby communities exist close to the project sites, distorting the balance of social dynamics and their environmental reflections. Land use furthermore affects the overall quality of life, as the projects occupy land that could potentially have been put into more beneficial uses for local communities. Extensive excavation, construction of new tunnels and roads and similar activities can further damage local habitat, especially if sensitive ecosystems are around. Power generation facilities that use biomass and biofuels in particular can directly or indirectly require large amounts of land. Therefore, land use should be thought as one of the decision criteriain such problems (Wang et al., 2009; Kahraman & Kaya, 2010; Kaya & Kahraman, 2011; Amer & Daim, 2011; Iskin et al., 2012).

- **Impact on Ecosystem**

Impact on ecosystem examines the potential risk to ecosystems. A rapidly growing energy demand can exert pressure on policy makers to disregard environmental impacts of power generation. However, the overall impact is not limited to one single criterion and each energy technology shall be assessed in a holistic manner. Any such assessment requires a good understanding about the whole system and the relations with in; otherwise, limited considerations can be misleading which might cause unexpected consequences in the longer term. As an example, potential risks posed by wind turbines to avian can be given (Kahraman & Kaya, 2010; Talinli et al., 2010; Amer & Daim, 2011).

3.2 A New Evaluation Model Proposition from Investor Perspective

As mentioned in previous section, model development is one of the main activities in thesis. Based on literature review, views of experts and academicians RER selection model is developed and then after the updates made the model has been revised according to investor perspective. Three DMs-(Experts namely Expert 1, Expert 2 and Expert 3 are constructed as an expert committee for the selection process.

Expert 1 (DM1) is an energy expert with over 12 years of experience in assessing sustainability aspects of renewable energy investments in Turkey. He works closely with local and international energy investors during project planning and operation phases.

Expert 2 (DM2) is a sustainable energy and climate finance expert with significant experience in project origination, project design documentation and carbon trade. She worked with various public and private sector agencies on the financial design and preparation of various environment and infrastructure projects. She worked with international organizations and finance institutions for developing sustainable finance strategies whereas she participated in sustainable energy and environmental finance public policy processes with the governments.

Expert 3 (DM3) gained relevant experiences in developing more than 80 emission reduction projects, preparation of monitoring plans for 10 facilities in different sectors within the scope of Turkish MRV Regulation, preparation of carbon footprint reports and GHG reduction roadmaps and preparation of water footprint, water risk assessment and water efficiency reports. He has also experiences of Climate Adaptation & Resiliency Projects and development of wind, solar and biogas national and international projects.

Based on industrial expert’s opinions Foreign Dependency, Compatibility with National Energy Policy Objectives, Social Benefits, Job Creation and Impact on Ecosystem criteria are removed from the initial model. Experts recommend revenue and Financial Structure and Know-How Cost. Then, Social and Political Aspects are combined and finally investor perspective model is developed. Fifteen sub-criteria are retained and grouped into four main criteria and the network diagram is presented in Figure 3.1.

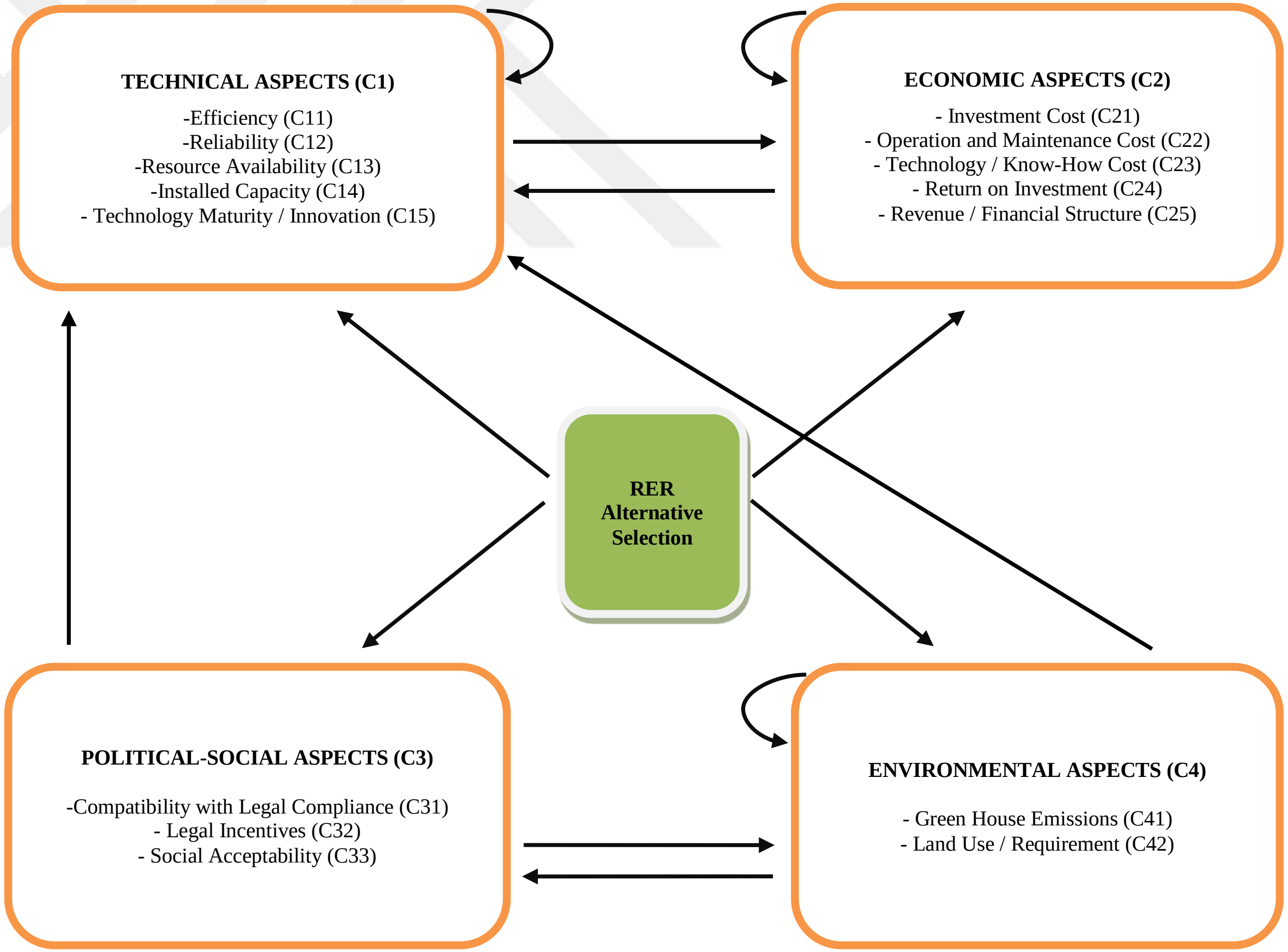

Figure 3.1: The RER selection network of investor perspective model

4. APPLICATION OF GDM BASED INTEGRATED DEMATEL, ANP AND TOPSIS

4.1 Literature Review

The GDM based integrated DEMATEL, ANP and TOPSIS techniques are frequently used in literature for solving MCDM problems. Table 4.1 summarizes these studies underlining their research scopes.

Table 4.1: GDM based integrated DEMATEL, ANP and TOPSIS studies

Year	Author(s)	Aim of the study	Analysis techniques	GDM	Type
2010	Chen & Chen	To develop innovation support system	DEMATEL, Fuzzy ANP, TOPSIS	+	Case study
2010	Lin et al.	To evaluate vehicle telematics system	DEMATEL, ANP, TOPSIS	+	Case study
2011	Kuo & Liang	To select the location of an international distribution center in Pacific Asia	DEMATEL, Fuzzy ANP, TOPSIS	+	Illustrative example
2012	Büyüközkan & Çifçi	To propose an evaluation framework for green suppliers	Fuzzy DEMATEL, Fuzzy ANP, Fuzzy TOPSIS	+	Case study
2014	Alimardani et al.	To select supplier in a system	DEMATEL, ANP, TOPSIS	-	Case study
2014	Chyu & Fang	To select the best color calibration device for a company	Fuzzy DEMATEL, Fuzzy ANP, TOPSIS	-	Case study
2015	Ju et al.	To select urban fire emergency alternative	DEMATEL, ANP, TL-TOPSIS	-	Illustrative example
2015	Uygun et al.	To measure institutionalization readiness of small and medium sized enterprises	Fuzzy DEMATEL, Fuzzy ANP, TOPSIS	+	Case study
2016	Bongo	To mitigate air traffic congestion	Fuzzy DEMATEL, ANP, Fuzzy TOPSIS	-	Case study
2016	Vinodh et al.	To select agile concept in manufacturing organizations	Fuzzy DEMATEL, Fuzzy ANP, Fuzzy TOPSIS	-	Case study
2016	Keramati & Shapouri	To evaluate customer relationship performance	DEMATEL, ANP, TOPSIS	-	Case study
2016	Varmazyar et al.	To measure the performance evaluation of research and technology organizations	DEMATEL, ANP, TOPSIS	-	Illustrative example
2016	Uygun & Dede	To measure the performance evaluation of green supply chain management	Fuzzy DEMATEL, Fuzzy ANP, Fuzzy TOPSIS	+	Case study

In literature, integrated DEMATEL, ANP and TOPSIS techniques are applied in different areas (logistics, education, supply chain etc.). In last year, in particular, there are many studies that use DEMATEL, ANP, TOPSIS methods together to overcome the individual weaknesses of using one method only, which are offset by the strength of the other method in real-life problems. However, these types of studies were not found in the renewable energy sector literature. Büyüközkan and Güleryüz (2016b) utilized combined DEMATEL and ANP framework but TOPSIS is not considered. Therefore this approach contributes to literature by filling the gap of RER selection problem from investor perspective in DEMATEL, ANP and TOPSIS applications for the first time.

4.2 Framework of GDM Based Integrated DEMATEL, ANP and TOPSIS

GDM based integrated DEMATEL, ANP and TOPSIS approach is selected as a systematic analytic framework to determine the proposed RER evaluation model. The overview of the GDM based integrated DEMATEL, ANP and TOPSIS approaches is given in Figure 4.1.

Firstly, evaluation criteria, sub-criteria and available alternatives are determined. This is accomplished with the help of experts' opinions and an extensive literature review. Then, if there are inner dependencies between criteria and sub-criteria DEMATEL is chosen otherwise ANP is utilized. GDM is then sought from a committee of DMs. Based on the information received from DMs, possible criteria that have an impact on the decision objective are determined. First, pair-wise comparisons are received from DEMATEL and the inner dependency structure is constructed and represented with looped arcs. Traditional DEMATEL steps are done, then traditional ANP steps are adopted to overcome the feedback and dependence problems among criteria and alternatives. Finally, all values are integrated to the supermatrix by entering the vectors obtained from DEMATEL and ANP into the appropriate column. Here criteria weights are calculated and are ready for TOPSIS steps. TOPSIS is utilized for the ranking of alternatives and the framework is concluded with the selection of most appropriate alternative.

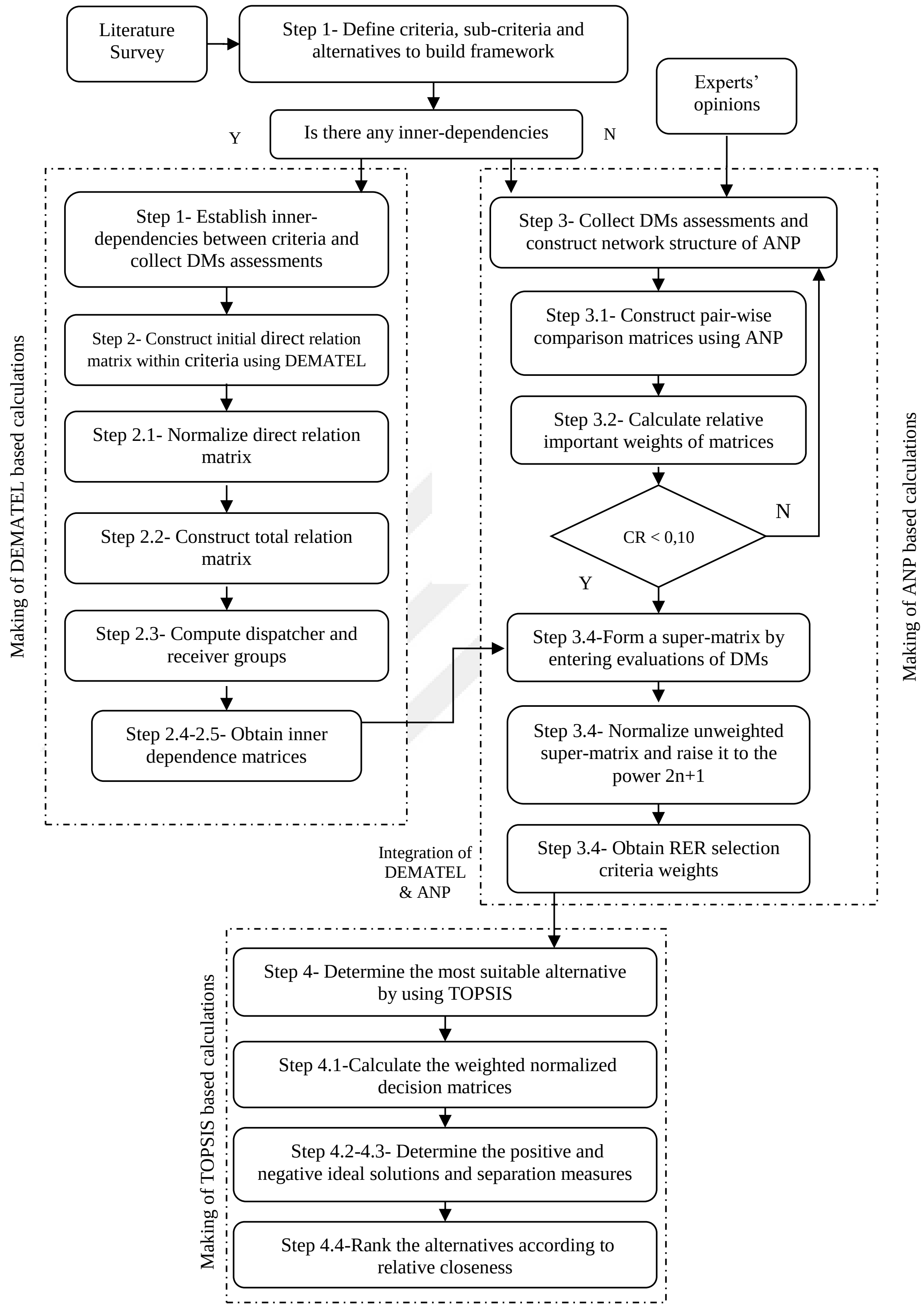

Figure 4.1: A general view of GDM based integrated DEMATEL, ANP and TOPSIS

4.3 Computational Steps of GDM Based Integrated DEMATEL, ANP and TOPSIS

Step 1: Define the objective, criteria, sub-criteria and alternatives of the evaluation model: The evaluation criteria are obtained through literature survey, experts' knowledge, experience, and other appropriate methods.

Step 2: Construct direct-relation matrix using DEMATEL: For comparing the relative importance degrees of components, a comparison scale is selected. The comparison scale consists of the following levels: No Influence (0), Low Influence (1), Medium Influence (2), High Influence (3) and Very High Influence (4). DMs are required to compare criteria pair-wise in terms of influence and direction. These evaluations are used to construct a matrix with dimension of n x n, called direct-relation matrix A. Here, a_{ij} stands for the degree to which the criteria *i* has an effect on criteria *j* (Büyüközkan & Öztürkcan, 2010) .

Step 2.1: Normalize the direct-relation matrix: The direct-relation matrix A is used to calculate the normalized direct relation matrix M, using the Equation (4.1) and (4.2).

$$M=k \times A \tag{4.1}$$

$$k=\min\left(\frac{1}{\max\limits_{1\leq i\leq n}\sum_{j=1}^{n}|a_{ij}|},\frac{1}{\max\limits_{1\leq j\leq n}\sum_{i=1}^{n}|a_{ij}|}\right)\quad i,j \in \{1,2,3,\ldots n\} \tag{4.2}$$

***Step 2.2*:** Calculate the total-relation matrix: Once M, the normalized direct-relation matrix, is obtained, the following Equation (4.3) is used to compute the total-relation matrix S, in which I is the identity matrix.

$$\begin{aligned} S&=M+M^2+M^3+\ldots=\sum_{i=1}^{\infty\leftarrow} M^i \\ &=M(I-M)^{-1} \end{aligned} \tag{4.3}$$

***Step 2.3*:** Calculate dispatcher and receiver groups. The dispatcher is calculated from the D-R which have positive values and higher influence on one another. They are assumed to exhibit higher priority and are thus referred as dispatcher groups, where R is the sum of columns and D is the sum of rows in matrix S, as highlighted in Equations (4.4)-(4.6). The other values with negative values of D-R, which do receive more influence from another, are considered to have a lower priority and are thus known as receiver groups. The value of D+R here shows the relation degree between each criterion with others. Those criteria that are exhibiting higher D+R values mean having more relationship with another and those having lower D+R values mean having less of a relationship with others.

$$S=\left[S_{ij}\right]_{nxn} \quad i,j \in \{1,2,3,\ldots n\} \tag{4.4}$$

$$D=\sum_{j-1}^{n} S_{ij} \tag{4.5}$$

$$R=\sum_{i=1}^{n} S_{ij} \tag{4.6}$$

***Step 2.4*:** Set a threshold value and construct the impact diagraph map: By mapping the dataset of the (D+R, D-R), the impact-diagraph map is obtained. Here, the horizontal axis indicates D+R and the vertical axis indicates D-R. In order to have an appropriate diagram, DMs must set an influence level threshold value. As the influence level in matrix S is higher than the threshold value, it can be converted into the impact-diagraph map.

***Step 2.5*:** Obtain the inner dependence matrix: Using the normalization method, the sum of each column in the total-relation matrix is equal to 1.

***Step 3*:** Construct the network of the considered problem and evaluate the remaining nodes and alternatives using the ANP.

Step 3.1: Calculate the relative weights of criteria and establish a pair-wise comparison matrix: For the pair-wise comparisons, the 9-point priority measurement scale by Saaty (1980) is used. This scale from 1 to 9 represents pairs of equal importance (1), up to extreme inequality in importance (9). A DM has different ways of making a declaration between each pair of element's relative dominance namely as: equally important, moderately more important, strongly more important, very strongly more important, and extremely more important. These judgments can be translated into numerical values 1,3,5,7,9 respectively and 2,4,6, and 8 can be identified as intermediate values for comparisons between two successive points. Hence, reciprocals of these values are used for the corresponding transpose judgments.

***Step 3.2*:** Calculate the eigenvalues and eigenvectors of the comparison matrix. Suppose that there are N criteria (C_1,.,C_i,.,C_n) and the pair-wise comparison matrix A = a_{ij}, where a_{ij} stands for the relative importance of criteria C_i and C_j. For all *i* and *j*, it is necessary that a_{ii}=1 and $a_{ij}=1/a_{ji}$.The row vector average method, introduced by Saaty (1980), is used to normalize the results, and the approximate weight W_i is calculated in Equation (4.7) as follows:

$$W_i=\frac{\sum_{j=1}^{n}\left(\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right)}{n} \quad (4.7)$$

$$\forall \; i,j = 1,2,..,n$$

Here, the comparison matrix A completely responds to $a_{ik}=a_{ij}.a_{jk}$ ∀ *i*,*j*,*k*. The following Equation (4.9) can be applied to obtain the approximate value of the largest eigenvalue λ_{max}.

$$AW=\lambda W \quad (4.8)$$

$$\lambda_{max}=\frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \quad (4.9)$$

***Step 3.3*:** Check consistency test: The consistency index (C.I.) and consistency ratio (C.R.) are used to estimate the consistency of the pair-wise comparisons via Equations (4.10) and (4.11).

$$C.I.=\frac{\lambda_{max}-n}{n-1} \quad (4.10)$$

$$C.R.=\frac{C.I.}{R.I.} \quad (4.11)$$

Given that the C.R. is thus less than 0,1; the pair-wise comparisons are for this reason acceptable, otherwise they are not acceptable. R.I. represents the average index for randomly generated weights. When the number of levels in the hierarchy is n = 2,…,8, R.I is 0,00; 0,58; 0,90; 1,12; 1,24; 1,32; 1,41 respectively.

***Step 3.4*:** Form a supermatrix by entering the vectors obtained from DEMATEL and ANP evaluations into the appropriate column: A supermatrix is defined as a partitioned matrix, in which every sub-matrix consists of relationships between two clusters. Local priority vectors are presented in the corresponding columns in the supermatrix. This supermatrix is first made stochastic (i.e. “weighted supermatrix”, where each column sums to 1). Following that, this “weighted supermatrix” is raised to its limiting powers until the weights converge to stable values, thus forming the “limit supermatrix”. By normalizing supermatrix blocks, eventual priorities are obtained (Büyüközkan & Çifçi, 2012).

***Step 4*:** Determine the most suitable alternative by using TOPSIS. First, calculate the normalized decision matrix. The evaluations of DMs evaluations are normalized the normalized value r_{ij} is calculated as:

$$r_{ij}= f_{ij} \Big/ \sqrt{\sum_{j=1}^{J} f_{ij}^{2}} \qquad (4.12)$$

$j=1,\ldots J;\ i=1,..,n$

***Step 4.1**:* Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as:

$$v_{ij}=w_i r_{ij},\ j=1,\ldots J; i=1,..,n, \qquad (4.13)$$

where w_i is the weight of the ith attribute or criterion, and $\sum_{i=1}^{n} w_i = 1$.

Step 4.2: Determine the positive ideal and negative-ideal solutions.

$$A^{+}=\{v_1^{+},\ldots,v_n^{+}\} \qquad (4.14)$$

$$=\left\{\left(\max_{j} v_{ij} \middle| i \in I'\right),\ \left(\min_{j} v_{ij} \middle| i \in I''\right)\right\}$$

$$A^{-}=\{v_1^{-},\ldots,v_n^{-}\}$$
$$\left\{\left(\min_{j} v_{ij} \middle| i \in I'\right),\ \left(\max_{j} v_{ij} \middle| i \in I''\right)\right\} \tag{4.15}$$

where I' is allied with benefit criteria, and I'' is allied with cost criteria.

Step 4.3: Calculate the separation measures, using the n dimensional Euclidean distance. The separation of each alternative from the ideal solution is provided as:

$$D_j^{+}=\sqrt{\sum_{i=1}^{n}\left(v_{ij}-v_i^{+}\right)^2},\ j=1,\ldots J \tag{4.16}$$

Similarly, the separation from the negative ideal solution is given as:

$$D_j^{-}=\sqrt{\sum_{i=1}^{n}\left(v_{ij}-v_i^{-}\right)^2},\ j=1,\ldots J \tag{4.17}$$

Step 4.4: Calculate the relative closeness to the ideal solution and rank the alternatives in descending order of the relative closeness. The relative closeness is defined as:

$$C_j^{*}=D_j^{-}/\left(D_j^{*}+D_j^{-}\right),\ j=1,\ldots J \tag{4.18}$$

4.4 Application of GDM Based Integrated DEMATEL, ANP and TOPSIS

Step 1: The objective, criteria, sub-criteria and alternatives of the decision making problem are determined in Section 3.

The determined four criteria and fifteen sub-criteria are listed as; Technical Aspects (C1) include Efficiency (C_{11}), Reliability (C_{12}), Resource Availability (C_{13}), Installed Capacity (C_{14}) and Technology / Maturity Innovation (C_{15}). Economic Aspects (C2) consist of Investment Cost (C_{21}), Operation and Maintenance Cost (C_{22}), Technology / Know-How

Cost (C_{23}), Return on Investment (C_{24}) and Revenue and Financial Structure (C_{25}). Political and Social Aspects (C3) include Compatibility with Legal Compliance (C_{31}), Legal Incentives (C_{32}) and Social Acceptability (C_{33}). Environmental Aspects (C4) involve Greenhouse Emissions (C_{41}) and Land Use / Requirement (C_{42}). Finally, the five possible alternatives are determined as Wind (A1), Solar (A2), Biogas (A3), Hydro (A4) and Geothermal (A5) energies.

Step 2: In the decision process, investors make pair-wise comparisons according to given scale of DEMATEL in Section 4.3. In this process Delphi method is used to reach a common decision. The initial direct relation matrices for all criteria, which have inner dependencies, are produced in this step. Not all matrices are shown here due to space limitations, as an example, the initial direct relation matrix of Economic Aspects, which include C21, C22, C23, C24 and C25, are given in Table 4.2.

Table 4.2: The initial direct relation matrix for Economic Aspects

	C21	C22	C23	C24	C25
C21	0,000	4,000	3,000	1,000	1,000
C22	4,000	0,000	3,000	1,000	1,000
C23	1,000	2,000	0,000	2,000	2,000
C24	0,000	0,000	2,000	0,000	3,000
C25	2,000	0,000	1,000	0,000	0,000

Step 2.1: The normalized matrix in Table 4.3 is calculated using the Equation (4.1) and (4.2) according to initial direct relation matrix.

Table 4.3: The normalized direct relation matrix for Economic Aspects

	C21	C22	C23	C24	C25
C21	0,000	0,444	0,333	0,111	0,111
C22	0,444	0,000	0,333	0,111	0,111
C23	0,111	0,222	0,000	0,222	0,222
C24	0,000	0,000	0,222	0,000	0,333
C25	0,222	0,000	0,111	0,000	0,000

Here, using the values provided in Table 4.2 and k is calculated as 0,111.

Step 2.2: Once M, the normalized direct-relation matrix, is obtained, the total-relation matrix S is found by using Equation (4.3) and shown in Table 4.4. Here Di shows the row sum and Ri shows the column sum.

Step 2.3: With the help of Equations (4.4)-(4.6), Di-Ri and Di + Ri values are calculated and given in Table 4.4.

Table 4.4: Total relation matrix for Economic Aspects

	C21	C22	C23	C24	C25	D_i	D_i+R_i	D_i-R_i
C21	0,750	1,030	1,134	0,561	0,748	4,22	7,362	1,084
C22	1,058	0,722	1,134	0,561	0,748	4,22	7,124	1,322
C23	0,594	0,616	0,583	0,486	0,648	2,93	6,701	-0,848
C24	0,284	0,236	0,494	0,168	0,557	1,74	3,693	-0,216
C25	0,455	0,297	0,428	0,179	0,238	1,60	4,536	-1,342
R_i	3,139	2,901	3,774	1,954	2,939			

Step 2.4: In agreement with the computed data in the previous step, the impact diagram map for economic aspects is constructed by using data set (Di+Ri, Di-Ri). Here, the horizontal axis indicates Di+Ri and the vertical axis indicates Di-Ri. The impact- diagraph map for the total relation of Economic Aspects is presented in Figure 4.2. Here, Di+Ri is the sum of the relationships among all elements that shows the importance of each element in the overall relationship.

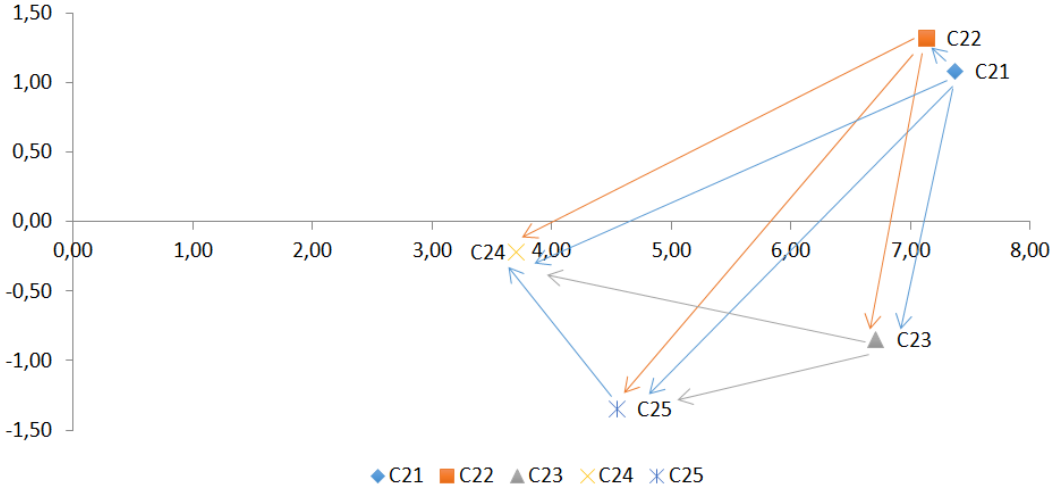

Figure 4.2: The impact-diagraph map of the total relations for Economic Aspects

The results indicate that C21 and C22 are dispatchers and C23, C24 and C25 are receivers. From Table 4.4 it is seen that the C21 (Investment Cost) has the value of (D_{21}– R_{21}= 1,084) and is regarded as an important cause as it influences all the others with a high importance (D_{21}+ R_{21}= 7,362).

Step2.5: According to the results obtained, it is seen that there is strong inner dependencies among Economic Aspects criteria. The inner dependence matrix is presented in Table 4.5 and the following criteria are examined in the same way.

Table 4.5: The inner dependences of Economic Aspects

	C21	C22	C23	C24	C25
C21	0,239	0,355	0,301	0,287	0,254
C22	0,337	0,249	0,301	0,287	0,254
C23	0,189	0,212	0,154	0,249	0,221
C24	0,090	0,081	0,131	0,086	0,189
C25	0,145	0,102	0,113	0,091	0,081

Step 3: Obtain the evaluation model: The notation for the sub-matrix can be seen in Table 4.6.

Table 4.6: General sub matrix notation for supermatrix

	G	TA	EA	P-SA	ENA
Goal (G)	0	0	0	0	0
Technical Aspects (TA)	Y	G	B	S	K
Economic Aspects (EA)	A	C	D	W	0
Political-Social Aspects (P-SA)	T	H	0	0	M
Environmental Aspects (ENA)	Z	0	0	R	L

The network structure of the evaluation model is constructed and summarized in previous section in Figure 3.1. Here, D, G and L present inner dependencies, which are utilized in DEMATEL steps and the remaining feedback and inter dependencies, are utilized in ANP step.

Step 3.1: To reach at the weight of each criterion ANP is applied in this step. The DMs can give judgments in numerical mode using Saaty's 1–9 scale. Due to space limitations, not all matrices are shown here. As an example, Economical Aspects are presented. The pair-wise comparison matrix of Economic Aspects (C node) is shown in Table 4.7.

Table 4.7: Economic Aspects with respect to Efficiency

	C21	C22	C23	C24	C25
C21	1,000	6,000	4,000	9,000	9,000
C22	0,167	1,000	0,200	5,000	5,000
C23	0,250	5,000	1,000	7,000	7,000
C24	0,111	0,200	0,143	1,000	1,000
C25	0,111	0,200	0,143	1,000	1,000

Step 3.2: With the help of Equation (4.7)-(4.9) the relative weights are computed as (0,521; 0,131; 0269; 0,039; 0,039). The parameter λ_{max}, which is the maximum eigenvalue in pair-wise comparison matrix, is found to be 0,544.

Step 3.3: In this step, the consistency of judgments are checked within the pair-wise comparison matrix. The results indicate the following; n=5, R.I =1,12; λ_{max}=0,544 and C.I.= 0,110; hence with the help of Equation (4.10) and (4.11) C.R. is calculated as 0,098. If C.R.<0,10, the degree of consistency is acceptable. In this case, it gives meaningful results. Therefore, the DMs judgments are sufficiently consistent enabling their use in the calculations in weighting estimates for various criteria.

Step 3.4: The consistency ratios of matrices are checked and the priority vectors are provided in the corresponding columns of the supermatrix. Using the priorities calculated with DEMATEL (with bold values) and ANP, the initial supermatrix is found, as shown in Table 4.8. The weighted supermatrix is transformed first to be stochastic. The supermatrix is then increased to sufficient large power until convergence occurs once the normalized values have been entered into the super matrix and completing the stochastic column. For this case application, the super matrix is raised to its 10^{th} and the resulting limit matrix is formed and can be seen in Table 4.9.

Table 4.8: The initial supermatrix of GDM based integrated DEMATEL, ANP and TOPSIS

	GOAL	C11	C12	C13	C14	C15	C21	C22	C23	C24	C25	C31	C32	C33	C41	C42
GOAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C11	0,536	**0,016**	**0,010**	**0,005**	**0,098**	**0,005**	0,058	0,234	0,089	0,104	0,030	0,054	0,113	0,039	0,122	0,103
C12	0,062	**0,096**	**0,120**	**0,537**	**0,201**	**0,537**	0,036	0,189	0,180	0,173	0,169	0,037	0,105	0,037	0,092	0,036
C13	0,182	**0,076**	**0,336**	**0,177**	**0,355**	**0,177**	0,123	0,085	0,083	0,234	0,252	0,401	0,098	0,162	0,030	0,291
C14	0,182	**0,156**	**0,103**	**0,054**	**0,030**	**0,054**	0,584	0,079	0,072	0,104	0,143	0,254	0,087	0,303	0,289	0,388
C15	0,038	**0,656**	**0,431**	**0,227**	**0,316**	**0,227**	0,199	0,413	0,576	0,385	0,406	0,254	0,597	0,459	0,467	0,182
C21	0,160	0,510	0,476	0,142	0,173	0,038	**0,224**	**0,366**	**0,308**	**0,293**	**0,251**	0,078	0,049	0,068	0,000	0,000
C22	0,085	0,135	0,223	0,264	0,091	0,164	**0,347**	**0,246**	**0,316**	**0,301**	**0,258**	0,053	0,084	0,033	0,000	0,000
C23	0,030	0,275	0,223	0,504	0,408	0,585	**0,182**	**0,209**	**0,140**	**0,240**	**0,206**	0,602	0,572	0,215	0,000	0,000
C24	0,529	0,040	0,039	0,039	0,031	0,041	**0,085**	**0,070**	**0,112**	**0,070**	**0,203**	0,049	0,055	0,208	0,000	0,000
C25	0,196	0,040	0,039	0,051	0,297	0,172	**0,162**	**0,109**	**0,124**	**0,096**	**0,082**	0,218	0,240	0,476	0,000	0,000
C31	0,198	0,197	0,311	0,468	0,280	0,554	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,292	0,105
C32	0,705	0,739	0,589	0,058	0,657	0,263	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,613	0,301
C33	0,097	0,064	0,100	0,474	0,063	0,183	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,095	0,594
C41	0,100	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,333	0,667	0,200	**0,389**	**0,522**
C42	0,900	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,667	0,333	0,800	**0,611**	**0,478**

Table 4.9: The weighted supermatrix results of RER selection problem

C11	**C12**	**C13**	**C14**	**C15**
0,029	0,080	0,071	0,066	0,149
C21	**C22**	**C23**	**C24**	**C25**
0,084	0,082	0,119	0,029	0,055
C31	**C32**	**C33**	**C41**	**C42**
0,060	0,063	0,035	0,035	0,044

The results shows that C15 (Technology Maturity / Innovation) rank as the first and the rest is C23 (Technology / Know-How Cost) and C12 (Reliability). Therefore, investors should focus on Technology Maturity / Innovation criteria.

Step 4: In Application of TOPSIS steps, the preliminary information comes from the DEMATEL and ANP. In decision process, DMs are expected to do evaluations in Saaty's scale and the evaluations of alternatives are given in Table 4.10.

Table 4.10: Linguistic evaluation data of alternatives

	C11	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C25**	**C31**	**C32**	**C33**	**C41**	**C42**
A1	B	VG	EG	VB	VG	G	EG	EG	VG	G	G	M	VG	G	G
A2	M	EG	EG	VVB	G	M	EG	VG	G	B	VG	M	EG	G	M
A3	EG	VG	MD	VVB	G	MD	G	M	G	B	VG	G	VG	EG	EG
A4	G	G	G	EG	EG	EG	VG	EG	EG	VG	VG	G	VB	G	MD
A5	EG	EG	EG	MB	VG	MB	VG	G	VG	MB	VG	G	G	MD	EG

Step 4.1: In this step, normalized decision matrix and weighted normalized matrix is calculated by using Equation (4.12) and (4.13).

Step 4.2 - 4.3: Positive ideal and negative ideal solutions are determined according to Equation (4.14) and (4.15) and separation measures are determined according to Equation (4.16) and (4.17).

Step 4. 4: The final step involves the ranking the RER alternatives in accordance with their closeness to the ideal solution by using Equation (4.18). The performance indices are calculated to rank the alternatives and the results obtained are portrayed in Table 4.11.

From the evaluations of experts by using DEMATEL, ANP, TOPSIS the most appropriate alternative is found as Hydro energy.

Table 4.11: Ranking of RER alternatives

Alternatives	**S^+**	**S^-**	**CC_i**	Ranking
Wind	0,045	0,040	0,473	2
Solar	0,065	0,029	0,309	4
Biogas	0,069	0,023	0,252	5
Hydro	0,021	0,071	**0,773**	1
Geothermal	0,045	0,038	0,458	3

According to Table 4.11, the scores of the alternatives are 0,773; 0,473; 0,458; 0,309 and 0,252 and the rank of the alternatives best to worst is Hydro, Wind, Geothermal, Solar and Biogas respectively.

4.5 Analysis of Obtained Results

The developed evaluation framework can help investors and researchers in reaching useful judgements and gaining research insights. Obtaining influential weights with DEMATEL the impact - diagraph map for the total relations are drawn. In previous section D arrow includes Economic Aspects is presented in Figure 4.2. The results indicate that C21 and C22 are dispatchers and C23, C24 and C25 are receivers. From Table 4.4 it is seen that the C21 (Investment Cost) has the value of (D_{21}– R_{21}= 1,084) and is regarded as an important cause as it influences all the others with a high importance (D_{21}+ R_{21}= 7,362).

In arrow G it is seen that Technical Aspects is considered in Figure 4.3. It is seen that, C13 and C15 are dispatchers and C11, C12 and C14 are receivers.

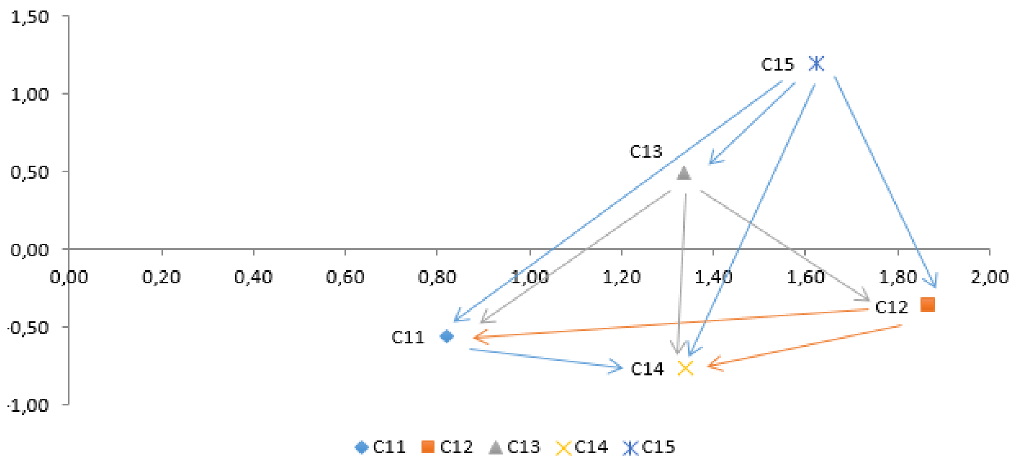

Figure 4.3: The impact-diagraph map of the total relations for Technical Aspects

From calculations C15 (Technology Maturity / Innovation) has the value of (D_{15}–R_{15}= 1,198) and is regarded as an important cause as it influences all the others with a high importance (D_{15}+R_{15} = 1,622).

C13 (Resource Availability) has (D_{13}–R_{13}= 0,489) and is in cause group. Therefore, investors should focus on Technology Maturity / Innovation and Resource Availability criteria.

In arrow L it is seen that Environmental Aspects is considered in Figure 4.4. Here, C41 is dispatcher and C42 is the receiver.

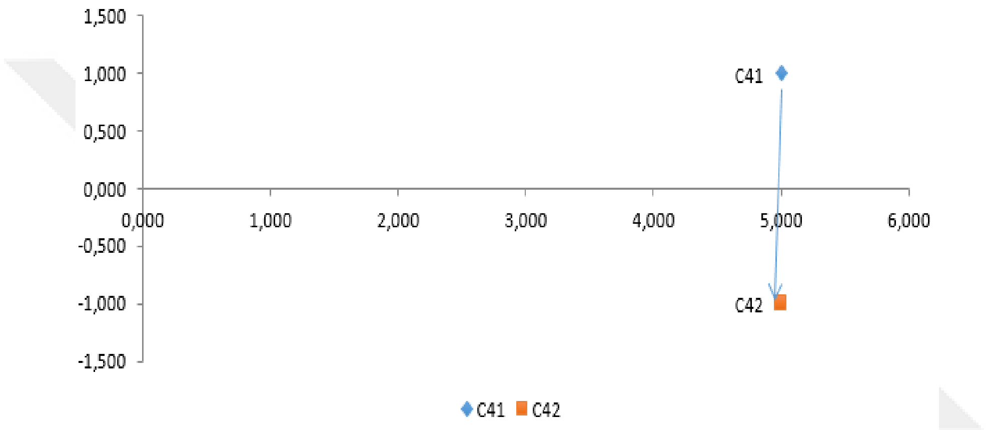

Figure 4.4: The impact-diagraph map of the total relations for Environmental Aspects

After analyzing the relationships between sub-criteria by DEMATEL, then criteria weights are calculated with ANP and results are given in Table 4.9. According to calculated final weights, Technical Aspects has a weight of 0,395; Economic Aspects has a weight of 0,368; Political & Social Aspects has a weight of 0,158 and Environmental Aspects has a weight of 0,079. It is seen that the most important criterion is Technical Aspects. It is followed by Economic Aspects > Political & Social Aspects > Environmental Aspects. After obtaining the weights of the criteria, DMs compare the alternatives with respect to each criterion with TOPSIS. Table 4.11 indicates that investors should invest Hydro Energy and the remaining alternatives are ranked as Wind > Geothermal > Solar > Biogas.

5. APPLICATION OF GDM BASED INTEGRATED LINGUISTIC INTERVAL FUZZY PREFERENCE RELATIONS WITH DEMATEL, ANP AND TOPSIS

Values of linguistic information can include words, phrases or sentences instead of numbers (Tapia García et al., 2012). Particular key advantages of a linguistic assessment are its flexibility, practicality, suitability to real world problems and its sufficiency to reflect the qualitative aspects in DM problems (Rodríguez et al., 2013). However, in some situations, DMs may face difficulties in estimating their preference degrees precisely in a numerical format. In other words, experts can find it difficult to assign a precise score to an alternative in decision making process. Under these circumstances, linguistic interval fuzzy preference relations can be used to describe experts' opinions with GDM in order to reach consensus under uncertainty. The theory of linguistic interval fuzzy preference relations has been first proposed by Xu (2001). It is designed to manage linguistic data, which is difficult to determine in decision process. This approach allows DMs to offer all possible evaluations in an interval and manage linguistic data which is difficult to determine in decision process (Tapia Garcia et al., 2012).

5.1 Literature Review

Recent literature shows that researchers are increasingly focusing on GDM by using linguistic interval fuzzy preference relations. Based on the literature, several studies have been applied satisfactorily to different research areas and these publications are provided in Table 5.1.

According to literature, it is seen that researchers are increasingly utilizes linguistic preference relations with MCDM techniques. Amongst listed literature, Suo et al. (2012) used DEMATEL method to an uncertain linguistic environment. Yuen and Lau (2009) utilized ANP with linguistic possibility approach in R&D selection.

Table 5.1: Linguistic interval fuzzy preference relations with GDM studies

Year	Author(s)	Aim of the study	Applied techniques	Application area	Type
2008	Jianqiang & Xiaohong	A new method proposition related with WC-OWA	Linguistic interval fuzzy preferences	-	Illustrative example
2008	Xu & Chen	A new model development issue in fuzzy environment	Interval fuzzy preference relation, multiplicative transitivity	-	Illustrative example
2010	Genç et al.	Tanino's method development and control of consistency	Interval and incomplete fuzzy preference relations	-	Illustrative example
2011	Xu	Measurement of linguistic interval fuzzy preferences	Linguistic interval fuzzy preferences, Quadratic programming	Defending industry	Illustrative example
2011	Liu et al.	Research study of fuzzy preference relations	MADM, interval probability	Investment	Illustrative example
2012	Chen et al.	To correct disadvantages of Mata et al. (2009)'s propositions	Fuzzy linguistic with 2 tuples, consensus	-	Illustrative example
2012	Tapia García et al.	Proposition of new consensus approach	Linguistic interval fuzzy preferences,	-	Illustrative example
2013	Liu	Development of new linguistic operators and theoretical studies	Interval intuitionistic uncertain linguistic variables	-	Illustrative example
2013	Lan et al.	Proposition of new model related with GDM in fuzzy environment	Linguistic variables, fuzzy environment	Finance	Illustrative example
2013	Zhang	Theoretical study of MADM and 2 tuples linguistic variables	Linguistic aggregation technique	-	Illustrative example
2014	Büyüközkan & Güleryüz	Selection of the most suitable RER for Turkey	Linguistic interval fuzzy preferences	Renewable energy	Case study
2014	Wang et al.	-	Interval Valued 2-tuple Linguistic information, Choquet integral	-	Illustrative example
2015	Franco et al.	-	2-tuple linguistic information, Choquet integral	University	Illustrative example
2016	Meng et al.	Proposition of new consistency-based programming model	Linguistic interval fuzzy preferences	-	Illustrative example
2016	Massanet et al.	Proposition of a novel definition of preference relations	Subjective evaluation, Linguistic fuzzy preferences	Medical	Illustrative example
2017	Büyüközkan & Güleryüz	Selection of the most appropriate RER for Turkey	Linguistic interval fuzzy preferences	Renewable energy	Case study
2017	Zhao et al.	Proposition of a more reasonable method to aggregate the preference relations	Linguistic fuzzy preferences, incomplete preferences	-	Illustrative example

Dağdeviren and Yüksel (2010) referred fuzzy ANP with linguistic variables in order to measure the sector completion level. Lin et al. (2010) presented an integrated ANP-QFD approach to find out environmental production requirements. Although there are studies and applications in linguistic forms with illustrative examples, integrated MCDM with linguistic interval fuzzy preferences is still missing link in literature. There are some applications that focus on this area concerned entirely with MCDM techniques separately such as Büyüközkan and Güleryüz (2014) considered GDM and AHP in linguistic interval fuzzy preferences. Franco (2014) also utilized linguistic preferences with AHP. Although there have been many studies and applications integrated to MCDM, Büyüközkan and Güleryüz's (2017) is the only study that proposes linguistic interval fuzzy preferences with DEMATEL ANP TOPSIS .

Literature on the area of linguistic interval fuzzy preference relations mainly focuses on operators in aggregation processes. Since the Ordered Weighted Averaging (OWA) operator was first generated by Yager (1988), many aggregation operators such as Linguistic Ordered Weighted Averaging (LOWA) operator (Herrera et al., 1995) has been developed. In the linguistic preference research, the mainly used operator is LOWA. It is used as an operator in order to aggregate non-weighted ordinal linguistic information. Another main importance of LOWA is that it uses order and linguistic assessment sets dealing with linguistic assessment and aggregation phrases through OWA and their extended forms (Herrera et al., 1995; Tapia Garcia et al., 2012).

5.2 Framework of GDM Based Integrated Linguistic Interval Fuzzy Preference Relations with DEMATEL, ANP and TOPSIS.

An overview of GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS is given in Figure 5.1 and Figure 5.2. The consensus reaching process starts with DMs evaluations. Here, DMs express their preferences with linguistic interval fuzzy preference relations and in order to aggregate these evaluations LOWA operator is utilized. It is used as an operator to aggregate non-weighted ordinal linguistic information. In this process, consensus relations of evaluations are formed then measurement of local degree of consensus and feedback mechanism is started. In this step if Linguistic Consensus Degree (LCD) is bigger than threshold value, the consensus is hold otherwise it is useful to calculate expert proximity relations in order to understated how much it deviates from agreement values. Next, it is necessary to look threshold value again in feedback mechanism. In this step, there may be some recommendations to expert in order to present reasonable consensus degree. Hence, if threshold value is fixed to a value and it satisfies evaluations, it can be said that the process reaches to consensus otherwise as a suggestion DMs should check their assessments.

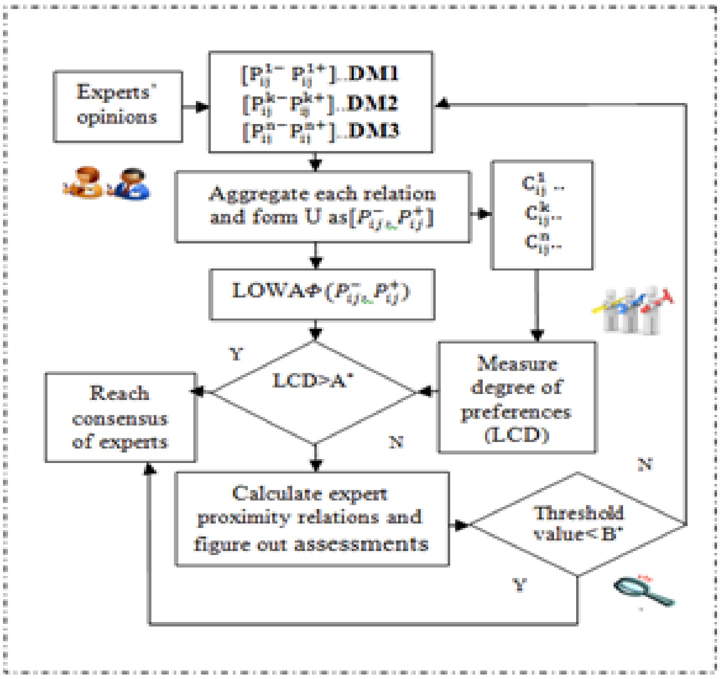

Figure 5.1: Flowchart of the linguistic interval fuzzy preference relations involving consensus reaching process

The summary approach of this framework begins with identifying the criteria used in evaluation and alternatives put forward using experts' opinion. A detailed literature review is presented for collecting information. Next, there is great need for the formation of a committee of experts in order to provide group decision. The scale is selected and the decision process has started. If dependencies between elements are seen ANP steps are done, otherwise in case of inner-dependencies DEMATEL is considered. After calculating fuzzy relative importance weights of matrices and measuring their consistencies, evaluations of DMs are formed. At this step, consensus reaching steps of ANP are done. Then, if the consistency does not hold, the preferences of DMs should be modified. At the same time, in case of inner-dependencies DEMATEL is considered. Consensus reaching steps of DEMATEL are done and then DEMATEL steps are adapted to this process.

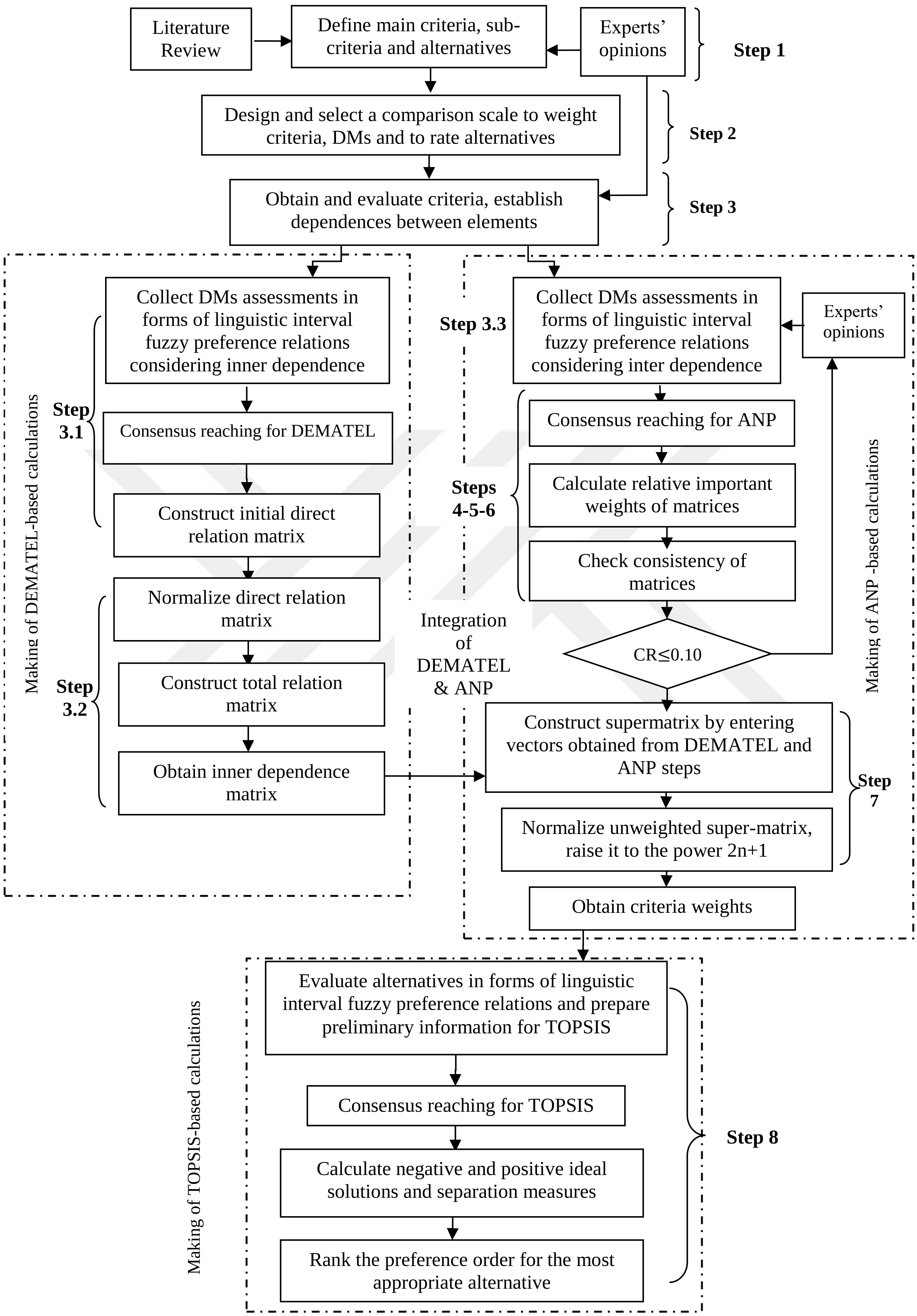

Figure 5.2: A general view of GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS

Inner dependencies matrix are calculated and finally, according to dependence of criteria and feedback relationships among their different levels, the vectors come from DEMATEL and ANP are integrated to the supermatrix. Next, the normalization of unweighted supermatrix is described. After raising unweighted supermatrix to the power of 2n+1, the weights are evaluated. Subsequently, TOPSIS is applied for ranking the available RER alternatives. At this stage, preliminary information concerning the relative importance of decision criteria is needed for applying TOPSIS.

5.3 Computational Steps of GDM Based Integrated Linguistic Interval Fuzzy Preference Relations with DEMATEL, ANP and TOPSIS.

Step 1**:** Define objective, criteria, sub-criteria and alternatives of the decision making problem. Then, construct a committee of DMs and establish the network structure for the evaluation.

Step 2**:** Design and select a comparison scale to weight criteria set and to rate alternatives. The nine linguistic label sets, as well as their associated semantics expressing linguistic interval fuzzy preferences are given in Table 5.2. The parameters are (a_i, b_i, α_i, β_i). Here, the first 2 parameters show the interval in which the membership value is 1. The 3rd and 4th parameters represent the distribution widths on its right and left sides. Here, each label s_i in a finite and totally ordered label set S = {s_0, . . . ,s_T},where odd cardinality is a possible value for a linguistic real variable.

Table 5.2: Corresponding linguistic terms for evaluation (Tapia Garcia et al., 2012)

Linguistic variables	Abbreviations	Fuzzy Scales
s_8 = C	Certain	(1,00 1,00 0,00 0,00)
s_7 = EL	Extremely Likely	(0,98 0,99 0,05 0,01)
s_6 = ML	Most Likely	(0,78 0,92 0,06 0,05)
s_5 = MC	Meaningful Chance	(0,63 0,80 0,05 0,06)
s_4 = IM	It May	(0,41 0,58 0,09 0,07)
s_3 = SC	Small Chance	(0,22 0,36 0,05 0,06)
s_2 = VLC	Very Low Chance	(0,10 0,18 0,06 0,05)
s_1 = EU	Extremely Unlikely	(0,01 0,02 0,01 0,05)
s_0 = I	Impossible	(0,00 0,00 0,00 0,00)

Step 3: Construct and calculate the pair-wise comparison matrices with the help of integrated DEMATEL and ANP with linguistic interval fuzzy preference relations. In order to reach a collective decision GDM approach is utilized and aggregation of collective linguistic interval fuzzy preference relations is carried out in this process.

Here, $X = \{x_1, x_2, . . . , x_n\} (n \geq 2)$ is defined as a finite set of alternatives, where each and every of these alternatives will be found by a finite set of DMs, $E = \{e_1, e_2, . . . , e_m\} (m \geq 2)$. A GDM approach has the goal to find the most appropriate alternative by taking DMs' preferences $\{P^1, P^2, . . . , P^m\}$ into account. After introducing these basic points, LOWA is used as an operator for aggregating non-weighted ordinal linguistic information. Suppose that $\{a_1, . . . , a_m\}$ is a set of labels to be aggregated. The LOWA operator ϕ, which will be used for the aggregation procedure, is formulated as:

$$\begin{aligned} \phi(a_1,..a_2) &= W \cdot B^T = C^m\{W_k, b_k, k=1,..,m\} \\ &= W_1 \odot b_1 \oplus (1-W_1) \odot C^{m-1}\{\beta_h, b_h, h=2,\ldots m\} \end{aligned} \tag{5.1}$$

where $W=\{W_1,\ldots,W_m\}$, is a weighting vector in a way that, $W_i \epsilon [0,1]$ and $\Sigma_i w_i=1$; $\beta_h = W_h / \Sigma_2^m w_k$, h=2,..m and B is defined as the associated ordered label vector. Each of the elements of vector ($b_i \epsilon$ B) is the i^{th} largest label in the set $a_1, . . . , a_m$. C_m is defined as the convex combination operator of m labels. In case m is 2, this operator can be formulated as follows:

$$C^2\{W_{i,} b_i, i=1,2\} = w_1 \odot s_j \oplus (1-w_1) \odot s_i = s_k, s_j, s_i \; S(j \geq i) \tag{5.2}$$

where k = min {T,i + round(w_1. (j - i))}, "round" standing for the mathematical rounding operation, and $b_1 = s_j$, $b_2 = s_i$. When w_j= 1 and w_i= 0 with $i \neq j$, then the convex combination becomes:

$$C^m\{W_{i,} b_i, k=1,\ldots,m\} = b_j \tag{5.3}$$

Next, U will be introduced. It represents the global preference between every ordered pair of alternatives according to the majority of DMs' opinions. For instance, in the case of the linguistic interval fuzzy preference relations U can be obtained as: $U = (U_{ij})$ for i,j=1,…,n.

$$U_{ij}=U\left[p_{ij}^{-},p_{ij}^{+}\right]=\left[\phi\_(p_{ij}^{k-}),\phi_{+}(p_{ij}^{k+})\right] \tag{5.4}$$

$$=\left[\min_k(p_{ij}^{k-}),\max_k(p_{ij}^{k+})\right] \text{ for } k=1,\ldots,n \tag{5.5}$$

With $w_-=\{0,\ldots,0,1\}$ in ϕ_- and $w_+ = \{1,0,\ldots,0\}$ in ϕ_+

Then, obtain exploitation phase and select the more preferable value. The dominance degree px_i is computed with the collective linguistic interval fuzzy preference relation, which can be formulated as:

$$P_{xi}=\sum_{\substack{j=1\\ j\neq i}}^{n}\left(s\left(p_{ij}^{-}\right)+s\left(p_{ij}^{+}\right)\right) \tag{5.6}$$

Step 3.1: Conduct consensus and proximity measures of the model: In this part, consensus indicators are computed with the help of the following steps:

Firstly, the consensus relations of each DM e^k, called C^k, is computed as;

$$C^k=C_{ij}^{k}=\left(\left|s\left(p_{ij}^{k-}\right)-s\left(p_{ij}^{-}\right)\right|+\left|s\left(p_{ij}^{k+}\right)-s\left(p_{ij}^{+}\right)\right|\right)/T \quad \text{For } i,j=1,\ldots,n \tag{5.7}$$

Here, each of the C_{ij}^{k} indicates the agreement degree of the expert e^k with the group of DMs on the preference p_{ij} and T represents the number that is possible to be in scale. Secondly, the linguistic global consensus degree of a preference, LCD is defined as:

$$\sum_{i=1}^{n} LCD_i=1-\sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n}\sum_{k=1}^{m} C_{ij}^{k}\ /((n^2-n)m)=CD \tag{5.8}$$

Then F_k, expert proximity relations with respect to the collective preference relation U is calculated as:

$$F^k = F^k_{ij} \text{ with}$$

$$F^k_{ij} = \left(s\left(p^{k-}_{ij}\right) - s\left(p_{ij}\right), s\left(p^{k+}_{ij}\right) - s\left(p_{ij}\right) \right) \Rightarrow = \left(f^{k-}_{ij}, f^{k+}_{ij}\right) \quad (5.9)$$

For i,j =1,…,n and $p_{ij} = \phi_Q\left(p^-_{ij}, p^+_{ij}\right)$ and $s\left(p_{ij}\right) = n$

If $p_{ij} = s_n$.Then, the proximity measure of the expert e^k on a preference p_{ij} is defined as:

$$PM^k_{ij} = \left(\left|f^{k-}_{ij}\right| + \left|f^{k+}_{ij}\right|\right)/2T \quad (5.10)$$

After that, the proximity measure of the expert e^k in an alternative x_i is defined as:

$$PM^k_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} PM^k_{ij}/(n-1) \quad (5.11)$$

Then, the global proximity measure of the expert e^k is defined as:

$$PM^k = \sum_{i=1}^{n} PM^k_i/(n) \quad (5.12)$$

***Step 3.2*:** Checking consistencies and doing feedback processes: DMs can change their opinions with the help of a feedback mechanism by using proximity relations matrices F^k. To reach a consensus, this mechanism provides a good control of consistencies and if there are inconsistencies the expert's preferences should be revised. In these processes, global consensus degree LCD need to be compared and a consensus threshold A is fixed. If LCD > A or LCD = A, then the consensus process will come to an end. Otherwise, in case LCD < A, then a new consensus round will be initiated until DM opinions sufficiently converge.

Step 4: If there are inner dependencies between criteria, DEMATEL is chosen and the remaining should be evaluated with ANP steps. Firstly DEMATEL is used to establish casual relations. As producing the direct-relation matrix and then continue with normalizing the direct-relation matrix M which can be constructed using Equation (5.13)-(5.14).

$$M = k \times A \tag{5.13}$$

$$k = \min\left(\frac{1}{\max\limits_{1\leq i\leq n} \sum_{i=1}^{n} |a_{ij}|}, \frac{1}{\max\limits_{1\leq i\leq n} \sum_{j=1}^{n} |a_{ij}|}\right) \tag{5.14}$$

Step 4.1**:** Acquire the total-relation matrix. After the normalized direct-relation matrix M is found, the total-relation matrix S will be formed with the formulae below, where I denotes the identity matrix.

$$S = M + M^2 + M^3 + \ldots = \sum_{i=1}^{\infty\leftarrow} M^i \tag{5.15}$$

$$= M(I-M)^{-1} \tag{5.16}$$

Step 5**:** Evaluate the remaining nodes and alternatives using the ANP. Linguistic terms and the corresponding fuzzy numbers are used to represent the relative level of strength for every pair of elements. In this step, the same procedure of ANP in previous section is utilized and Equation (4.7) is used to evaluate criteria weights.

Step 6**:** Form a super-matrix of ANP model: The initial super-matrix is constructed by using the priorities which are calculated by linguistic interval fuzzy preferences with DEMATEL and ANP. After the initial supermatrix is obtained, the columns are normalized in such a way that the values in each column add up to 1. The overall priorities of elements can be found by multiplying the sub-matrixes repeatedly until the matrix columns stabilize and converge to the same values in the sub-matrix blocks. This means that calculation of the overall priorities is achieved by raising the un-weighted supermatrix to its limiting powers. Finally, the cumulative influence of each element on every other element with which it interacts is found.

***Step 7**:* Identifying the most suitable alternative among different partners by using linguistic interval within TOPSIS. Proposed integrated technique requires preliminary information on the relative importance of decision criteria, which can be identified with ANP-DEMATEL within linguistic preferences. In addition to this, TOPSIS steps are adapted from the previous section and the relative closeness coefficient (CC_i) is calculated by the operations described in the previous section. In this step, rank the alternatives according to descending order of CC_i values. Here, the chosen alternative has the maximum value of CC_i.

5.4 Application of GDM Based Integrated Linguistic Interval Fuzzy Preference Relations with DEMATEL, ANP and TOPSIS

Step 1: In section 3 it is seen that the creation of a decision committee made up of three experts to determine the most appropriate RER among five possible alternatives.

Step 2: In this step, the scale is utilized from Tapia Garcia and his colleagues' study as given in Table 5.2. (Tapia García et al., 2012).

Step 3: The pair-wise comparison matrices are constructed with the help of linguistic interval fuzzy preference relations. The relations among the elements of this structure are found with the help of DMs' linguistic evaluations, which are then converted into numerical values. Here, DMs analyze criteria according to their interest, expertise and their intuition. Due to space limitation not all matrices can be given. As an example, 3 DMs' evaluations of Economic Aspects with respect to the Goal (Node C) and their linguistic interval fuzzy preferences form are shown in Table 5.3, Table 5.4, and Table 5.5. Here, T = 8 (value number in scale), m = 3 (DM number) and n = 5 (Alternative number).

Step 3.1: Aggregation of collective linguistic fuzzy preference relations are calculated with the help of Equations (5.4) and (5.5). U is formed and presented in Table 5.6.

According to the normalization process by using Equation (5.6), the criteria weights of Economic Aspects; C1, C2, C3, C4 and C5 are calculated as 0,213; 0,169, 0,000, 0,400 and 0,219, respectively.

Table 5.3: Linguistic evaluation of DM1

	C1		C2		C3		C4		C5	
C1	-	-	MC	ML	C	C	I	I	SC	IM
C2	VLC	SC	-	-	C	C	I	I	EU	VLC
C3	I	I	I	I	-	-	I	I	I	I
C4	C	C	C	C	C	C	-	-	C	C
C5	IM	MC	ML	EL	C	C	I	I	-	-

Table 5.4: Linguistic evaluation of DM2

	C1		C2		C3		C4		C5	
C1	-	-	IM	MC	C	C	I	I	MC	ML
C2	SC	IM	-	-	C	C	I	I	VLC	SC
C3	I	I	I	I	-	-	I	I	I	I
C4	C	C	C	C	C	C	-	-	C	C
C5	VLC	SC	MC	ML	C	C	I	I	-	-

Table 5.5: Linguistic evaluation of DM3

	C1		C2		C3		C4		C5	
C1	-	-	SC	IM	C	C	I	I	IM	MC
C2	IM	MC	-	-	C	C	I	I	VLC	SC
C3	I	I	I	I	-	-	I	I	I	I
C4	C	C	C	C	C	C	-	-	C	C
C5	SC	IM	MC	ML	C	C	I	I	-	-

Table 5.6: Collective linguistic interval fuzzy preference relations

	C1		C2		C3		C4		C5	
C1	-	-	SC	ML	C	C	I	I	SC	ML
C2	VLC	MC	-	-	C	C	I	I	EU	SC
C3	I	I	I	I	-	-	I	I	I	I
C4	C	C	C	C	C	C	-	-	C	C
C5	VLC	MC	MC	EL	C	C	I	I	-	-

Consensus relations are calculated with Equations (5.7) and (5.8). According to these, DM1's consensus matrix is as follows:

$$C^1 = \begin{pmatrix} * & 0{,}250 & 0 & 0 & 0{,}250 \\ 0{,}250 & * & 0 & 0 & 0{,}125 \\ 0 & 0 & * & 0 & 0 \\ 0 & 0 & 0 & * & 0 \\ 0{,}250 & 0{,}125 & 0 & 0 & * \end{pmatrix}$$

The degree of global consensus is found as CD=1,25 and LCD is found as 0,929. Then, the consensus threshold is fixed as A=0,7 which means that the threshold ratio should not be less than 0,7. The consensus degree seems to be acceptable. If this is not the case, the DM should repeat the pair-wise comparison.

Step 3.2: Check the consistencies and perform feedback process. If the threshold value is fixed to 0,15; expert's assessments are approximate and consistent so that the collective fuzzy preference relations matrix (U) is suitable to indicate dominance degrees of each weight of criteria:

$$px_1 = 0{,}031 \quad px_2 = 0{,}025 \quad px_3 = 0{,}025.$$

***Step 4*:** If there are inner dependencies between criteria, DEMATEL is chosen and the remaining should be evaluated with ANP steps. Here, D, G, L are DEMATEL steps and example evaluations of L node is given in the following steps.

Table 5.7: Linguistic evaluations of DMs

DM1					DM2					DM3				
	C31		C32			C31		C32			C31		C32	
C31	-	-	SC	IM	C31	-	-	IM	IM	C31	-	-	IM	IM
C32	IM	MC	-	-	C32	IM	IM	-	-	C32	IM	IM	-	-

Table 5.8: Collective linguistic interval fuzzy preference relations

	C31		C32	
C31	-	-	SC	IM
C32	IM	MC	-	-

Consensus relations are calculated with Equations (5.7) and (5.8). According to these, LCD is calculated as 0,992 and the consensus degree seems to be acceptable. Then feedback process should be checked. If the threshold value is fixed to 0,15, expert's assessments are approximate and consistent so that the collective fuzzy preference relations matrix (U) is suitable to indicate dominance degrees of each weight of criteria: $px_1 = 0{,}060$; $px_2 = 0{,}060$ and $px_3 = 0{,}060$. Hence, U rounded calculates as $\begin{pmatrix} 0 & 4 \\ 5 & 0 \end{pmatrix}$. By using the Equations (5.15) and (5.16) inner dependence matrix is calculated.

Table 5.9: The inner dependence of Environmental Aspects

	C31	C32
C31	0,444	0,500
C32	0,556	0,500

Step 5: Evaluate the remaining nodes and alternatives using the ANP. In this step, the same procedure of ANP in step 3.1 and 3.2 done to all remaining criteria.

Step 6: Construct the supermatrix. First, an unweighted supermatrix is constructed by integrating priority vectors into the related columns in

Table 5.10. According to calculation steps, DEMATEL and ANP have to be formed and these priorities should be entered in to appropriate columns.

Table 5.10: The initial supermatrix of GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS

	GOAL	C11	C12	C13	C14	C15	C21	C22	C23	C24	C25	C31	C32	C33	C41	C42
GOAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C11	0,350	**0,200**	**0,390**	**0,704**	**0,383**	**0,351**	0,081	0,200	0,113	0,175	0,056	0,050	0,150	0,050	0,144	0,113
C12	0,081	**0,093**	**0,055**	**0,171**	**0,157**	**0,162**	0,081	0,200	0,206	0,206	0,200	0,050	0,150	0,050	0,144	0,006
C13	0,219	**0,158**	**0,287**	**0,055**	**0,303**	**0,276**	0,156	0,100	0,138	0,219	0,244	0,362	0,150	0,200	0,013	0,288
C14	0,219	**0,097**	**0,148**	**0,029**	**0,041**	**0,169**	0,401	0,100	0,144	0,119	0,163	0,269	0,150	0,300	0,300	0,362
C15	0,131	**0,452**	**0,120**	**0,041**	**0,116**	**0,042**	0,281	0,400	0,399	0,281	0,337	0,269	0,400	0,400	0,399	0,231
C21	0,213	0,399	0,400	0,169	0,200	0,050	**0,200**	**0,390**	**0,704**	**0,383**	**0,351**	0,100	0,100	0,113	0,000	0,000
C22	0,169	0,125	0,244	0,256	0,119	0,244	**0,093**	**0,055**	**0,171**	**0,157**	**0,162**	0,100	0,100	0,044	0,000	0,000
C23	0,000	0,288	0,244	0,375	0,387	0,400	**0,158**	**0,287**	**0,055**	**0,303**	**0,276**	0,400	0,400	0,244	0,000	0,000
C24	0,400	0,119	0,056	0,100	0,006	0,056	**0,097**	**0,148**	**0,029**	**0,041**	**0,169**	0,100	0,100	0,244	0,000	0,000
C25	0,218	0,069	0,056	0,100	0,288	0,250	**0,452**	**0,120**	**0,041**	**0,116**	**0,042**	0,300	0,300	0,355	0,000	0,000
C31	0,229	0,229	0,292	0,500	0,333	0,333	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,292	0,104
C32	0,667	0,667	0,604	0,000	0,667	0,667	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,604	0,292
C33	0,104	0,104	0,104	0,500	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,104	0,604
C41	0,125	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,313	0,687	0,188	**0,444**	**0,500**
C42	0,875	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,687	0,313	0,812	**0,556**	**0,500**

Following that, the unweighted supermatrix is normalized and raised to its 11th power. The weighted supermatrix is shown in Table 5.11.

Table 5.11: Weighted supermatrix

C11	C12	C13	C14	C15
0,081	0,056	**0,075**	0,073	**0,110**
C21	**C22**	**C23**	**C24**	**C25**
0,110	0,054	**0,099**	0,033	0,071
C31	**C32**	**C33**	**C41**	**C42**
0,050	0,082	0,027	0,038	0,041

The results shows that C15 (Technology Maturity / Innovation) rank as the first and the rest C21 (Investment Cost) rank as the first and the rest is C23 (Technology and Know-How Cost). Therefore, investors should focus on Technology Maturity / Innovation criteria.

Step 7: Application of TOPSIS steps. The preliminary information comes from the DEMATEL and ANP steps. The evaluations of alternatives are given in previous section in Table 4.10. From the evaluations of experts by using GDM based linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS the most appropriate alternative is found as hydro energy.

Table 5.12: Ranking of RER alternatives

Alternatives	**S^+**	**S^-**	**CC_i**	Ranking
Wind	0,058	0,049	0,457	3
Solar	0,081	0,029	0,262	5
Biogas	0,079	0,038	0,328	4
Hydro	0,020	0,085	**0,811**	1
Geothermal	0,052	0,051	0,494	2

According to Table 5.12 the scores of the alternatives are 0,811; 0,494; 0,457; 0,328 and 0,262 and the rank of the alternatives best to worst is Hydro, Geothermal, Wind, Biogas and Solar.

5.5 Analysis of Obtained Results

The developed evaluation framework can help investors and researchers in reaching useful judgements and gaining research insights. Obtaining influential weights with DEMATEL the impact - diagraph map for the total relations are drawn. As an example Economic Aspects which has arrow D are given in Figure 5.3.

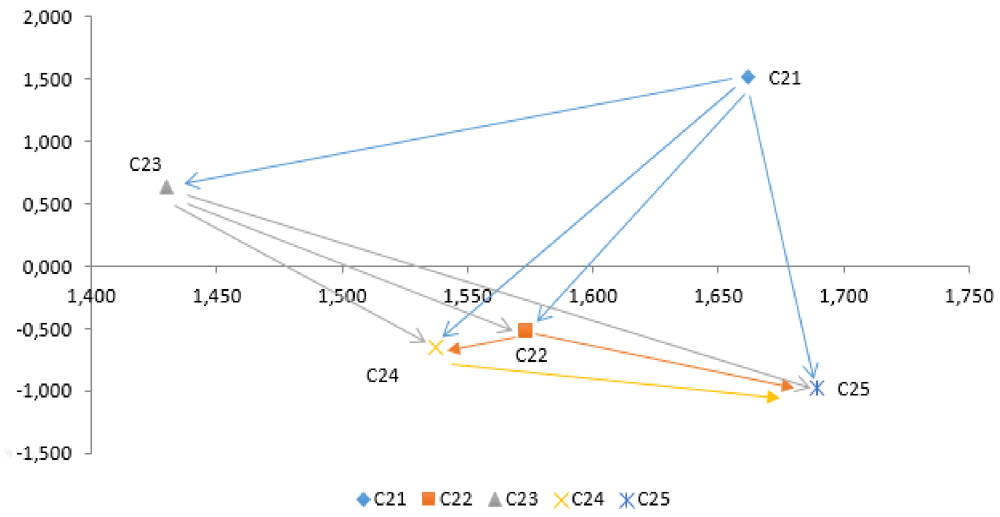

Figure 5.3: The impact-diagraph map of the total relations for Economic Aspects

The results indicate that C21 and C23 are dispatchers; C22, C24 and C25 are receivers. From According to the calculations, it is seen that the C21 (Investment Cost) has the value of (D_{21}– R_{21}= 1,516) and is regarded as an important cause as it influences all the others with a high importance (D_{21}+ R_{21}= 1,662). C23 (Technology and Know-how Cost) has (D_{23}– R_{23}= 0,637) and is in cause group. Therefore, investors should focus on Investment Cost and Technology and Know-How Cost.

According to the calculations, C11 and C13 are dispatchers and C12, C14 and C15 are receivers. From calculations C11 (Efficiency) has the value of (D_{11}– R_{11}= 1,516) and is regarded as an important cause as it influences all the others with a high importance (D_{11}+ R_{11} = 1,622). C13 (Resource Availability) has (D_{13}– R_{13}= 0,637) and is in cause group. Therefore, investors should focus on Efficiency and Resource Availability criteria.

Figure 5.4 shows the Environmental Aspects impact-diagraph. Here, C41 (Green House Emissions) is receiver and C42 (Land Use / Requirement) is dispatcher. It is seen that C42 is in an important cause as it influences the other criteria.

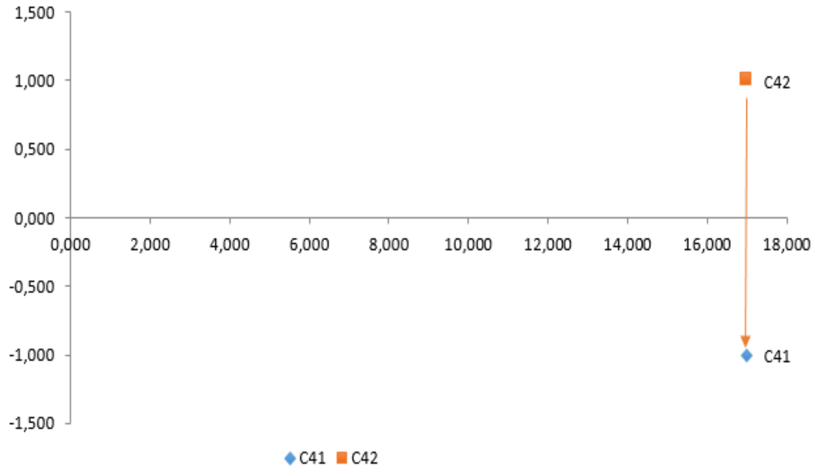

Figure 5.4: The impact-diagraph map of the total relations for Environmental Aspects

As soon as the analysis of the relationships between sub-criteria by DEMATEL, then criteria weights are calculated with ANP and results are provided in Table 4.9. According to calculated final weights, Technical Aspects has a weight of 0,395; Economic Aspects has weight of 0,368; Political and Social Aspects has a weight of 0,158 and Environmental Aspects has a weight of 0,079. It is seen that the most important criterion is Technical Aspects. It is followed by Economic Aspects > Political and Social Aspects > Environmental Aspects. After obtaining the weights of the criteria, DMs compare the alternatives with respect to each criterion with TOPSIS. Table 5.12 indicates that investors should invest Hydro Energy and the remaining alternatives are ranked as Geothermal > Wind > Biogas >Solar.

6. APPLICATION OF GDM BASED INTEGRATED IF-DEMATEL, IF-ANP AND IF-TOPSIS

In some situations, it is observed that fuzzy sets can be insufficient and problematic when they are used for processing human beings' subjective judgments and the associated ambiguity, such as the lack of accurate or sufficient knowledge in DMs, or the difficulty to formulate the degree to which one alternative is better than the others (Behret, 2014). In these cases, IFS are useful and practical tools that can work out these difficulties.

Proposed by (Atanassov, 1986), IFS can be defined as the generalization form of fuzzy sets. Different from fuzzy set theory, the data information assigns to every component a membership degree, a non-membership degree and a hesitancy degree (Jin et al., 2014).

6.1 Literature Review

Concretely in the process of GDM under dubiousness, the experts may emanate from different research and domains thus have different backgrounds and levels of erudition, skills, experience, and personality in many practical situations. Due to the fact that the experts may not have enough expertise which is very importantly required to precisely express their choice over the objects, whereby, they conventionally have some doubts in providing their predictions, which makes the results of cognitive performance portray the characteristics of affirmation, negation, and a certain degree of hesitation. During such instances, the data or choices that have been given by the DMs may be conveniently expressed in IF numbers. In other words DMs provide their preferences for the alternative to a certain degree and it is possible that they are not sure about it (Xu & Liao, 2014).

Therefore, it is more appropriate to express DMs preferences in the form of IFS. For example in MCDM, such as personnel evaluations, medical diagnosis, project investment analysis, etc. each IFS provided by the expert can be used to express both the degree that an alternative should satisfy a criterion and the degree that the alternative should not satisfy the criterion. One very advantageous aspect of the IFS is in describing uncertainty and vagueness of an object, which can be then, put underutilization as a formidable tool to express the data information under numerous different fuzzy environments, which has drawn great attentions (Xu & Xia, 2010).

Integration with GDM can be used to serve as an example in Xu & Liao (2014) research. They expressed that triangular fuzzy numbers; trapezoidal fuzzy numbers and interval-valued fuzzy numbers can only be habituated to depict the fuzziness of agreement but cannot reflect the disagreement of DM. However, in real life, human beings frequently dissent, which is a prevalent way for expressing their ideas. Hence, IFS copes with these situation and aggregate experts' opinions for collective decisions in GDM problems.

The pioneering works and the important contributions focusing on IF-DEMATEL, IF-ANP and IF-TOPSIS are summarized in the following paragraphs. Although there have been some studies related with IF-DEMATEL, different articles focus on different parts of IFS and also use different terms and methods. When Table 6.1 and above mentioned explanations are investigated, research contributions of papers can be summarized as follows: Firstly, GDM is very rare in IF-DEMATEL literature. The difference between the proposed methodology and the mentioned papers in Table 6.1 is that they consider a completely different approach applied within different aggregation steps. With the latest development, the present study Liu et al. (2015) applied the 2-tuple DEMATEL for the selection of health-care waste treatment alternatives. As a summary, proposed approach will be one of the very few studies which present IF-DEMATEL with GDM approach in literature.

Table 6.1: IF-DEMATEL studies

Year	Author(s)	Integrated approach(es)	GDM	Application area	Type
2010	Chang & Cheng	Failure Mode and Effects Analysis	-	Semiconducting manufacturing project evaluation	Illustrative example
2012	Li et al.	Failure Mode and Effects Analysis, Dempster-Shafer Theory	+	-	Illustrative example
2014	Li et al.	Dempster-Shafer Theory	-	Emergency management optimization	Case study
2014	Xie et al.	-	+	Course selection	Illustrative example
2014	Nikjoo & Saeedpoor	SWOT analysis	-	Insurance company's most important components determination	Case study
2015	Govindan et al.	-		Green supply chain practices evaluation	Case study
2015	Keshavarzfard & Makui	IF-AHP	-	Managers selection of automobile industry in Iran	Case study
2015	Sangaiah et al.	Dempster-Shafer Theory	+	Knowledge transfer effectiveness measurement of a software organization	Case study
2017	Zhou et al.	Dempster-Shafer Theory	+	Emergency management	Case study

Reviewing the literature on MCDM methods with IFS in Table 6.2 shows that, only one conference paper which is published by Saeedi et al. (2014) utilized IFS with ANP with very limited computational steps. This study considers completely different approach of ANP with geo-spatial information systems and they do not take IF-ANP calculations in to account in a detail way. In addition, GDM is not considered in their study. Hence the proposed approach fills the gap in literature.

As seen in Table 6.3, there is an integration of IF-TOPSIS with different techniques in various fields of application, in contrast, in energy sector the applications are limited.

Table 6.2: IF-AHP/ANP studies

Year	Author(s)	Intuitionistic type	Integrated approach(es)	GDM	Application area	Type
2009	Sadiq & Tesfamariam	IF-AHP	-	-	Best drilling fluid selection for drilling operations	Illustrative example
2012	Wang & Sun	IF-AHP	-	-	Energy management contract project evaluation	Case study
2014	Abdullah & Najib	IF-AHP	Entropy	+	Sustainable energy technology selection	Case study
2014	Abdullah & Najib	IF-AHP	Entropy	+	-	Illustrative example
2014	Kaur	IF-AHP	-	-	Vendor selection	Illustrative example
2014	Xu & Liao	IF-AHP	-	-	Global supplier development	Illustrative example
2014	Saeedi et al.	IF-ANP	-	-	Geo-spatial information systems	Case study
2015	Dutta et al.	IF-AHP	-		Sadiq & Tesfamariam's example	Illustrative example
2015	Keshavarzfard & Makui	IF-AHP	IF-DEMATEL	-	Automobile industry in Iran	Case study
2015	Liao & Xu	IF-AHP	-	+	Global supplier development	Illustrative example
2016	Tavana et al.	IF-AHP	SWOT		Reverse logistics	Case study
2016	Büyüközkan & Güleryüz	IF-AHP	IF-TOPSIS	+	Product development partner selection	Case study
2017	Büyüközkan & Göçer	IF-AHP	IF-Axiomatic Design	+	Supplier selection	Case study

6.2 Framework of GDM Based Integrated IF-DEMATEL, IF-ANP and IF-TOPSIS

An overview of the GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS approaches are given in Figure 6.1. One of the primary advantages of this proposed method is that it is a flexible and robust way for DMs to better understand a decision problem in case of uncertainty and vagueness in DMs perceptions.

Table 6.3: IF-TOPSIS studies

Year	Author(s)	Integrated approach(es)	GDM	Application area	Application type
2009	Boran et al.	-	+	Supplier selection	Illustrative example
2009	Boran	-	-	Personnel selection	Case study
2011	Boran	-	-	Facility location selection	Illustrative example
2011	Su et al.	-	-	3PL logistic provider selection	Illustrative example
2011	Ning & Wang	-	-	The best site layout selection	Case study
2012	Rouyendegh	Data Envelopment Analysis	-	University department performance measurement	Illustrative example
2012	Boran et al.	-	-	Renewable energy resource selection	Case study
2013	Vahdani et al.	ELECTRE	+	Flexible manufacturing systems selection	Illustrative example
2014	Kucukvar et al.	-	-	Asphalt pavement selection	Illustrative example
2014	Joshi & Kumar	-		Portfolio selection	Case study
2014	Maldonado-Macías et al.	AHP	-	Milling machine selection	Illustrative example
2014	Yue	-	-	Chinese universities' satisfaction evaluation	Illustrative example
2015	Cao et al.	-	-	Green supplier selection	Illustrative example
2015	H.-C. Liu et al.	Failure mode and effects analysis		Ranking failure modes of a product	Illustrative example
2016	Büyüközkan & Güleryüz	IF-AHP	+	Product development partner selection	Case study
2016	Büyüközkan & Güleryüz	-	+	Smart phone selection	Case study
2016	Gumus et al.	Entropy	-	Wind turbine selection	Case study
2016	Wood	Entropy	-	Supplier selection	Illustrative example

Another advantage is that with this method a collective decision is achieved by combining DMs' assignments in appropriate ways, based on a satisfactory degree of agreement by using GDM consistent with human thoughts.

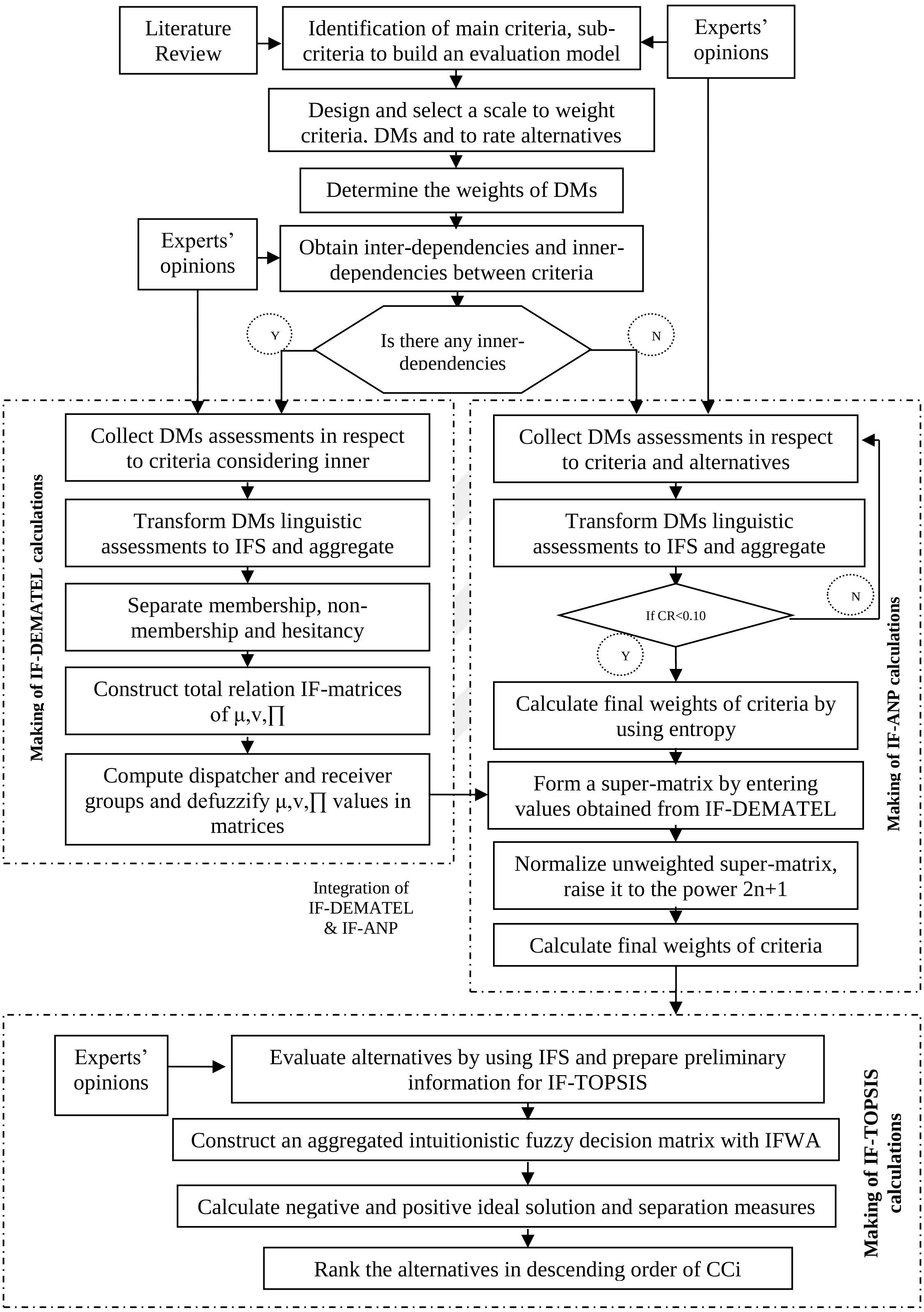

Figure 6.1: A general view of GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS

6.3 Computational Steps of GDM Based Integrated IF-DEMATEL, IF-ANP and IF-TOPSIS

The integrated IF DEMATEL, ANP and TOPSIS methodologies can be summarized in the following steps:

To understand this approach it is started by introducing some basic concepts which will be used throughout the new study area. As a definition, IFS A in a finite set X can be written as:

$$A=\left\{\langle x,\mu_A(x), v_A(x)\rangle\ x\in X\right\} \quad (6.1)$$

Where $\mu_A(x), v_{(A)}(x)$: $X\rightarrow[0,1]$ are “membership function” and “non-membership function” respectively such that,

$$0\leq\mu_A(x)+v_A(x)\leq 1 \quad (6.2)$$

A third parameter of IFS is $\pi(x)$, known as the intuitionistic fuzzy index or “hesitation degree” of whether x belongs to A or not

$$\pi_A=1-\mu_A(x)-v_A(x) \quad (6.3)$$

It is obviously seen that for every $x \in X$:

$$0\leq\pi_A(x)\leq 1 \quad (6.4)$$

If the $\pi_A(x)$ is small, knowledge about x is more certain. If $\pi_A(x)$ is great, knowledge about x is more uncertain. Obviously, when $\mu_A(x) = 1 - v_A(x)$ for all elements of the universe, the ordinary fuzzy set concept is recovered (Shu et al., 2006).

Let A and B are IFSs of the set X, then multiplication operator is defined as follows (Atanassov, 1986):

$$A \otimes B = \left\{ \mu_A(x).\mu_B(x), v_A(x).v_B(x) - v_A(x).v_B(x) I\ x \in X \right\} \quad (6.5)$$

<u>Step 1</u>: Define the objective, criteria and sub-criteria of the evaluation model. The evaluation criteria are obtained through literature survey, experts' knowledge. Then, set up a group of experts who have sufficient experience and knowledge.

<u>Step 2</u>: Design and select evaluation scale. Table 6.4 shows the definition of linguistic terms and their equivalent forms in terms of IFS that utilized in IF-DEMATEL steps. For IF-ANP, the evaluation scale proposed by (Abdullah & Najib, 2016) in Table 6.5 is used for transforming linguistic assessments of DMs for comparing relative importance degrees of components.

Table 6.4: Scale for IF-DEMATEL

Classical DEMATEL	Definition of Linguistic Terms	IFS		
4	Very High Influence (VH)	[0,90	0,10	0,00]
3	High Influence (H)	[0,75	0,20	0,05]
2	Medium Influence (M)	[0,50	0,45	0,05]
1	Low Influence (L)	[0,35	0,60	0,05]
0	No Influence (N)	[0,00	1,00	0,00]

Table 6.5: Scale for IF-ANP (Abdullah & Najib, 2014a)

Definition of Linguistic Terms	Preference Number	IFS
Equally Important (EI)	1	[0,02 0,18 0,80]
Intermediate Value (IV1)	2	[0,06 0,23 0,70]
Moderately More Important (MI)	3	[0,13 0,27 0,60]
Intermediate Value (IV2)	4	[0,22 0,28 0,50]
Strongly More Important (SI)	5	[0,33 0,27 0,40]
Intermediate Value (IV3)	6	[0,47 0,23 0,30]
Very Strong More Important (VSI)	7	[0,62 0,18 0,20]
Intermediate Value (IV4)	8	[0,80 0,10 0,10]
Extremely More Important (EMI)	9	[1,00 0,00 0,00]

Table 6.6 shows the definition of linguistic terms and their equivalent forms in terms of IFS.

Step 3: Determine the weights of DMs. In this approach, DMs' importance degrees may change according to their experience and knowledge about the subject. In the light of these, $D_k=[\mu_k, v_k, \pi_k]$ is defined as an intuitionistic fuzzy number for the rating of k^{th} DM.

Table 6.6: Scale for IF-TOPSIS and DMs weights evaluation

Linguistic Variables		Linguistic Variables		IFS		
				μ	υ	π
Extremely Unimportant	EU	Extremely Poor	EP	[0,00	0,95	0,05]
Very Unimportant	VU	Very Poor	VP	[0,05	0,90	0,05]
Unimportant	U	Poor	P	[0,25	0,70	0,05]
Somewhat Unimportant	SU	Moderately Poor	MP	[0,40	0,55	0,05]
Medium Importance	MI	Fair	F	[0,50	0,45	0,05]
Somewhat Important	SI	Moderately Good	MG	[0,60	0,35	0,05]
Important	I	Good	G	[0,75	0,20	0,05]
Very Important	VI	Very Good	VG	[0,90	0,05	0,05]
Extremely Important	EI	Extremely Good	EG	[0,95	0,00	0,05]

Importance degrees of these DMs are considered by using the IFS linguistic terms, as can be seen from Table 6.6. The weight of k^{th} DM is obtained using the Equation (6.6) (Boran et al., 2009).

$$\lambda_k=\frac{\left(\mu_k+\pi_k\left(\frac{\mu_k}{\mu_k+v_k}\right)\right)}{\sum_{k=1}^{l}\left(\mu_k+\pi_k\left(\frac{\mu_k}{\mu_k+v_k}\right)\right)} \quad \text{And} \quad \sum_{k=1}^{l}\lambda_k=1 \tag{6.6}$$

Step 4: Determine DMs' intuitionistic preference relations by considering inner dependences and interdependencies. If there are inner dependencies between criteria, IF-DEMATEL is chosen and the remaining should be evaluated with IF-ANP steps.

Step 5: Application of IF-DEMATEL steps.

***Step 5.1*:** Collect DMs assessments in respect to criteria considering inner dependences.

***Step 5.2*:** Determine DMs' intuitionistic preference relations, transform DMs linguistic assessments to IFS and construct aggregated intuitionistic fuzzy relation matrix. The procedure for GDM needs to aggregate DM's opinions in to a collective form. For this reason, IFWA operator (Xu, 2007) is utilized to aggregate DMs' evaluations for rating the levels of importance for each criterion. Here, W symbolizes the importance degree. Let $W_{ij}^{(k)}=\left[\mu_{ij}^{(k)},v_{ij}^{(k)},\pi_{ij}^{(k)}\right]$ be an IFS that is given by the kth DM to the criteria X_{jj}. The aggregation process is done by using Equation (6.7) with the IFWA operator (Xu, 2007) and the aggregated intuitionistic fuzzy relation is formulated as follows:

$$\begin{aligned} W_{ij} &= IFWA_{\lambda}\left(W_{ij}^{(1)}, W_{ij}^{(2)},..,W_{ij}^{(l)}\right) \\ &= \lambda_1 W_{ij}^{(1)} \oplus \lambda_2 W_{ij}^{(2)} \oplus \lambda_3 W_{ij}^{(3)} \oplus \ldots \oplus \lambda_l W_{ij}^{(l)} \\ &= \left[1-\prod_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(v_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k}, -\prod_{k=1}^{l}\left(v_{ij}^{(k)}\right)^{\lambda_k}\right] \quad (6.7) \\ W_{ij} &= \left[\mu_{Ai,}(x_j), v_{Ai}(x_j), \pi_{Ai}(x_j)\right] \; (j=1,2,..,n) \end{aligned}$$

***Step 5.3*:** Separate membership, non-membership and hesitancy values and then apply DEMATEL steps. First, form the direct-relation matrices of membership, non-membership and hesitancy values using inner-dependencies between criteria. DMs' evaluations are used to construct matrices with dimension of n x n, called initial direct-relation matrices $\tilde{x}^{(k)}$. Here, $\tilde{x}^{(k)}{}_{ij}$ is defined as the degree of criterion i's impact on the criterion j.

$$\tilde{x}^{(k)}=\begin{bmatrix} 0 & \tilde{x}^{(k)}{}_{12} & \tilde{x}^{(k)}{}_{13} & \cdots & x^{(k)}{}_{1n} \\ \tilde{x}^{(k)}{}_{21} & 0 & \tilde{x}^{(k)}{}_{23} & \cdots & \tilde{x}^{(k)}{}_{2n} \\ \tilde{x}^{(k)}{}_{31} & \tilde{x}^{(k)}{}_{32} & 0 & \cdots & \tilde{x}^{(k)}{}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{x}^{(k)}{}_{n1} & \tilde{x}^{(k)}{}_{n2} & \tilde{x}^{(k)}{}_{n3} & \cdots & 0 \end{bmatrix} \quad (6.8)$$

$$\tilde{x}^{(k)}_{ij,\ IFS}=\left(\mu_{ij}^{(k)}, v_{ij}^{(k)}, \pi_{ij}^{(k)}\right) \tag{6.9}$$

Second, normalize the direct-relation IF matrices of membership, non-membership and hesitancy values, $\tilde{X}^{(k)}$, which is found as below:

$$\tilde{X}=k \text{ x } \tilde{x}^{(k)} \tag{6.10}$$

$$k=\min\left(\frac{1}{\max_{1\le i\le n}\sum^{n}_{j=1}\left|\tilde{x}^{(k)}_{ij}\right|},\frac{1}{\max_{1\le i\le n}\sum^{n}_{j=1}\left|\tilde{x}^{(k)}_{ij}\right|}\right) \tag{6.11}$$

$$\text{for } i,j \in \{1,2,3,\ldots n\}$$

Step 5.4**:** Construct the total relation IF-matrices membership, non-membership and hesitancy values, using the normalized direct-relation IF-matrices. The following Equation (6.12) is used to construct the total-relation IF-matrix ($\tilde{T}$) in which I is the identity matrix (Keshavarzfard & Makui, 2015).

$$\tilde{T}=\tilde{X}+\tilde{X}^2+\tilde{X}^3+\ldots=\sum_{i=1}^{\infty\leftarrow}\tilde{X}^i$$

$$=\tilde{X}(I-\tilde{X})^{-1} \tag{6.12}$$

$$\tilde{T}=\begin{bmatrix}\tilde{t}_{11} & \tilde{t}_{12} & \tilde{t}_{13} & \cdots & \tilde{t}_{1n}\\ \tilde{t}_{21} & \tilde{t}_{22} & \tilde{t}_{23} & \cdots & \tilde{t}_{2n}\\ \tilde{t}_{31} & \tilde{t}_{32} & \tilde{t}_{33} & \cdots & \tilde{t}_{3n}\\ \vdots & \vdots & \vdots & \ddots & \vdots\\ \tilde{t}_{n1} & \tilde{t}_{n2} & \tilde{t}_{n3} & \cdots & \tilde{t}_{nn}\end{bmatrix}$$

Step 5.5**:** Compute dispatcher and receiver groups. The impact-diagraph is prepared by mapping the dataset formed by the horizontal axis (D+R) and vertical axis (D-R). The horizontal (D+R) axis denotes the significance of a factor. The vertical (D-R) axis helps to differentiate factors into either cause or effect groups. Usually, a positive (D-R) indicates a causal factor, whereas a negative (D-R) indicates a factor that is in the effect group. Thus, such causal diagrams can help convert complicated relationships into visible structural models, thereby providing valuable insight into complex decision problems.

$$S=[S_{ij}]_{nxn} \quad i,j \in \{1,2,3,\ldots n\} \tag{6.13}$$

$$D=\sum_{j-1}^{n} S_{ij} \tag{6.14}$$

$$R=\sum_{i=1}^{n} S_{ij} \tag{6.15}$$

Getting IF-DEMATEL values in appropriate columns of supermatrix normalization should be done. Then, defuzzify membership, non-membership and hesitancy values in obtained matrices using transformation formula proposed by (Xie et al., 2014) and given in Equation (6.16).

$$\bar{r}_{ij}= \mu_{ij}^{(k)}-v_{ij}^{(k)}+(2\beta-1)\pi_{ij}^{(k)} \tag{6.16}$$

The coefficient of risk preference (β) defines the proportion of hesitant person choose to support $\beta \in [0,1]$, and 1- β is the proportion of hesitant person choose to against. $\beta > 0,5$ means that the DM is risk appetite, $\beta < 0,5$ means the DM risk avoidance and $\beta = 0,5$ the DM is risk neutral.

<u>Step 6</u>**:** Application of IF-ANP steps.

<u>Step 6.1</u>**:** Collect DMs' assessments by considering interdependencies and reconstruct the network of the problem.

Step 6.2: Find DMs' intuitionistic preference relations and build aggregated intuitionistic fuzzy relation matrix with IFWA operator as it shown in Equation (6.7). Acquiring and aggregating the assessments of DMs pair-wise comparisons are elicited in this step.

Step 6.3: Check the consistency of each intuitionistic preference relation. In order to check intuitionistic preference relations consistency, the consistency ratio (CR) is calculated. Here, the aim is to estimate whether the pair-wise comparisons are consistent. If CR is less than 0,10; then it suggests that the comparisons are acceptable, otherwise (if CR is greater than 0,10) they are not acceptable and the values should be revised. Consistency value formula is adapted from the Abdullah and Najib's study (2016), as given in Equation (6.17) and the random index (RI) is utilized from Saaty (1996):

$$CR=\frac{(\lambda_{max}-n)/(n-1)}{RI} \tag{6.17}$$

Assume that $(\lambda_{max}-n)$ is the average of $\pi_{(x)}$ values, which is the aggregated IF matrix of each criterion. Here, n denotes the size of the matrix.

Step 6.4: Calculate IF entropy weights of the aggregated weighted IF decision matrix, as follows:

$$\bar{\bar{w}}_i=-\frac{1}{n\ln 2}\left[\mu_i \ln \mu_i+v_i \ln v_i-(1-\pi_i)\ln(1-\pi_i)-\pi_i \ln 2\right] \tag{6.18}$$

If $\mu_i=0$, $v_i=0$, $\pi_i=1$, then $\mu_i \ln \mu_i=0$, $v_i \ln v_i=0$, $(1-\pi_i)\ln(1-\pi_i)=0$ and
$\mu_i=1$, $v_i=0$, $\pi_i=1$, then $\mu_i \ln \mu_i=0$, $v_i \ln v_i=0$, $(1-\pi_i)\ln(1-\pi_i)=0$.

And the final entropy weights of each IF matrix is defined using the following Equation (6.19):

$$w_i = \frac{1-\overline{\overline{w}}_i}{n-\sum_{j=1}^{n}\overline{\overline{w}}_i} \quad (6.19)$$

$$\text{Where } \sum_{j=1}^{n}\overline{\overline{w}}_i = 1$$

Step 6.5**:** Form a supermatrix by entering the values obtained from IF-DEMATEL and IF-ANP evaluations into a suitable column: A supermatrix is defined as a partitioned matrix, in which every sub-matrix consists of relationships between two clusters. Local priority vectors are presented in the corresponding columns in the supermatrix. This supermatrix is first made stochastic (i.e. "weighted supermatrix", where each column sums to 1). Following that, this "weighted supermatrix" is raised to its limiting powers repeatedly until the weights converge to stable values, thus forming the "limit supermatrix". By normalizing supermatrix blocks, eventual priorities are obtained.

Step 7**:** Application of IF-TOPSIS steps. Evaluate alternatives by using IFS and prepare preliminary information for IF-TOPSIS.

Step 7.1**:** Construct aggregated weighted intuitionistic fuzzy decision matrices by using IFWA. After establishing necessary values, calculate the distances from positive and negative ideal points. Assume that, J_1 is the benefit criteria and J_2 is the cost criteria. With these, A^+ represents the intuitionistic fuzzy positive-ideal solution and A^- represents the intuitionistic fuzzy negative-ideal solution, which can be obtained as:

$$A^+ = \left((\mu_{A^+W}(x_j), v_{A^+W}(x_j) \right) \text{ and}$$
$$A^- = \left((\mu_{A^-W}(x_j), v_{A^-W}(x_j) \right) \quad (6.20)$$

where,

$$\mu_{A^+W}(x_j) = \left(\left(\max_i \mu_{A_i.W}(x_j) \mid j \epsilon J_1 \right), \left(\min_i \mu_{A_i.W}(x_j) \mid j \epsilon J_2 \right) \right) \quad (6.21)$$

$$v_{A^+W}(x_j)=\left(\left(\min_i v_{A_i.W}(x_j) \mid j\epsilon J_1\right),\ \left(\max_i v_{A_i.W}(x_j) \mid j\epsilon J_2\right)\right) \tag{6.22}$$

$$\mu_{A^-W}(x_j)=\left(\left(\min_i \mu_{A_i.W}(x_j) \mid j\epsilon J_1\right),\ \left(\max_i \mu_{A_i.W}(x_j) \mid j\epsilon J_2\right)\right) \tag{6.23}$$

$$v_{A-W}(x_j)=\left(\left(\max_i v_{A_i.W}(x_j) \mid j\epsilon J_1\right),\ \left(\min_i v_{A_i.W}(x_j) \mid j\epsilon J_2\right)\right) \tag{6.24}$$

***Step 7.2*:** Calculate the separation measures of IF sets of the alternatives. In this part, Euclidean distance is utilized to measure separation measures of the alternatives. The distance of the alternatives from positive and negative ideal points are computed as follows:

$$S^+=\sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[\left(\mu_{A_i.W}(x_j)-\mu_{A^+W}(x_j)\right)^2+\left(v_{A_i.W}(x_j)-v_{A^+W}(x_j)\right)^2+\left(\pi_{A_iW}(x_j)-\pi_{A^+W}(x_j)\right)^2\right]} \tag{6.25}$$

$$S^-=\sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[\left(\mu_{A_i.W}(x_j)-\mu_{A^-W}(x_j)\right)^2+\left(v_{A_i.W}(x_j)-v_{A^-W}(x_j)\right)^2+\left(\pi_{A_iW}(x_j)-\pi_{A^+W}(x_j)\right)^2\right]} \tag{6.26}$$

Here, S_i^+ represents the IF positive-ideal solution and S_i^- represents the IF negative-ideal solution.

***Step 7.3*:** Rank the alternatives according to descending order of CC_i values. Calculate the CC_i for the intuitionistic ideal solution. The CC_i of an alternative A_i with respect to A^+ is defined as follows:

$$CC_i=\frac{S_{i-}}{S_{i-}+S_{i+}} \tag{6.27}$$

In this method, the chosen alternative has the maximum value of CC_i.

6.4 Application of GDM Based Integrated IF-DEMATEL, IF-ANP and IF-TOPSIS

***Step 1*:** The model is based on a real life case study and model is discussed by researchers and some criteria are eliminated in order to make the model more efficient. Based on a detailed literature survey, the contribution of industrial experts, online journals, project reports and conference papers this study attempts to develop an appropriate model for selecting the most appropriate renewable energy alternative from investor perspective.

***Step 2*:** The linguistic scales for the evaluations are selected in previous section. In the decision process, DMs make pair-wise comparison with the help of Table 6.4 for IF-DEMATEL, Table 6.5 for IF-ANP. The alternatives evaluation are utilized from Table 6.6 for IF-TOPSIS.

***Step 3*:** The weights of DMs are determined by using Table 6.6 and Equation (6.6). The importance values of linguistic variables of the three DMs are: λ_1 presents as “extremely important, λ_2 presents as “very important”, λ_3 presents as “very important”. By applying Equation (6.6) the DMs’ weights are found as 0,346; 0,327 and 0,327 respectively. Detailed information on the experts is given in detail in the Section 3.2.

***Step 4*:** Determine DMs’ intuitionistic preference relations. If there is any inner dependence between criteria, DMs are expected to make pair-wise comparisons according IF-DEMATEL otherwise IF-ANP should be considered.

***Step 5*:** Application of IF-DEMATEL.

***Steps 5.1-5.2*:** After collecting DMs evaluations, transform their assessments to IFS and then aggregate intuitionistic fuzzy relation matrices. Here, Table 6.7 shows the linguistic evaluation matrix of loop “D” for DM1. By using IFWA operator, opinions are aggregated into a collective form in Table 6.8.

Table 6.7: Linguistic evaluation matrices of loop D for DM1

	C21	C22	C23	C24	C25
C21	N	VH	H	L	L
C22	VH	N	H	L	L
C23	L	M	N	M	M
C24	N	N	M	N	H
C25	M	N	L	N	N

Table 6.8: Aggregated IF judgment matrices of 3 DMs' assessments in loop D

C21			C22			C23			C24			C25		
μ	**v**	∏	**μ**	**v**	∏	**μ**	**v**	∏	**μ**	**v**	∏	**μ**	**v**	∏
0,000	1,000	0,000	0,818	0,157	0,025	0,750	0,200	0,050	0,350	0,600	0,050	0,350	0,600	0,050
0,865	0,125	0,010	0,000	1,000	0,000	0,750	0,200	0,050	0,350	0,600	0,050	0,350	0,600	0,050
0,350	0,600	0,050	0,455	0,494	0,050	0,000	1,000	0,000	0,455	0,494	0,050	0,455	0,494	0,050
0,000	1,000	0,000	0,000	1,000	0,000	0,406	0,543	0,050	0,000	1,000	0,000	0,750	0,200	0,050
0,500	0,450	0,050	0,000	1,000	0,000	0,350	0,600	0,050	0,000	1,000	0,000	0,000	1,000	0,000

***Step 5.3*:** First, the direct-relation matrices of membership, non-membership and hesitancy values using inner-dependencies between criteria are formed. Then by using Equation (6.10) and (6.11) normalize the direct-relation IF-matrices of membership, non-membership and hesitancy values separately. Due to space limitations, not all calculations are shown here. As an example membership values of initial matrix and its direct relation matrix are presented in Table 6.9 and Table 6.10.

Table 6.9: Formed μ values of aggregated IF judgement matrices

	C21	C22	C23	C24	C25
C21	0,000	0,818	0,750	0,350	0,350
C22	0,865	0,000	0,750	0,350	0,350
C23	0,350	0,455	0,000	0,455	0,455
C24	0,000	0,000	0,406	0,000	0,750
C25	0,500	0,000	0,350	0,000	0,000

***Step 5.4*:** Once the normalized initial direct-relation matrices are obtained, the total-relation matrix ($\tilde{T}$) is found with the Equation (6.12) as presented in Table 6.11.

Table 6.10: The initial direct relation IF matrix of μ

	C21	C22	C23	C24	C25
C21	0,000	0,353	0,324	0,151	0,151
C22	0,374	0,000	0,324	0,151	0,151
C23	0,151	0,197	0,000	0,197	0,197
C24	0,000	0,000	0,176	0,000	0,324
C25	0,216	0,000	0,151	0,000	0,000

Table 6.11: The total relation matrix for economic aspects of μ

	C21	C22	C23	C24	C25	D+R	D-R
C21	0,576	0,745	0,954	0,539	0,713	6,15	0,90
C22	0,861	0,495	0,969	0,547	0,724	5,71	1,48
C23	0,536	0,484	0,499	0,449	0,594	5,82	-0,70
C24	0,231	0,161	0,403	0,138	0,507	3,30	-0,42
C25	0,422	0,234	0,433	0,184	0,244	4,30	-1,27

***Step 5.5*: ** After the total relation IF-matrices are calculated, dispatcher and receiver groups are formed, and the causal diagrams, are constructed by mapping the dataset of the (D+R, D-R). The values of μ are calculated in Table 6.11 and the (D+R, D-R) value of v and ∏ are calculated as the same way.

It is important to know the values of DEMATEL are intuitionistic numbers and before placing the appropriate column in the supermatrix these values should be defuzzified by using Equation (6.16). The defuzzified matrix is presented in Table 6.12.

Table 6.12: Defuzzified matrix of μ for node D

	C21	C22	C23	C24	C25
C21	0,280	0,183	0,193	0,226	0,238
C22	0,176	0,270	0,196	0,229	0,240
C23	0,207	0,182	0,281	0,186	0,201
C24	0,223	0,195	0,177	0,199	0,142
C25	0,114	0,170	0,153	0,161	0,179

Getting IF-DEMATEL values in appropriate columns of supermatrix normalization should be done by Equation (6.16). Due to space limitations, not all calculations are shown here.

***Step 6*: ** Evaluate the network of the considered problem and calculate the weights of the remaining criteria by using IF-ANP. The notation for the sub-matrix can be seen in Table 6.13. Here, the relations for comparisons are shown with letters.

Table 6.13: General sub matrix notation for supermatrix

	G	TA	EA	P-SA	EA
Goal (G)	0	0	0	0	0
Technical Aspects (TA)	Y	G	B	S	K
Economic Aspects (EA)	A	C	D	W	0
Political-Social Aspects (P-SA)	T	H	0	0	M
Environmental Aspects (EA)	Z	0	0	R	L

***Steps 6.1-6.2*: ** Here, when transforming linguistic assessments of DMs in Table 6.14, Table 6.6 is utilized. Then, IFWA operator given in Equation (6.7) is utilized to aggregate the assessments of DMs pair-wise comparisons. The aggregated collective intuitionistic fuzzy judgment matrices are shown in Table 6.15.

Table 6.14: Linguistic evaluation matrices with respect to Goal of A

	C21	C22	C23	C24	C25	C21	C22	C23	C24	C25	C21	C22	C23	C24	C25
C21	-	IV2	VSI		IV1	-	IV2	IV3		EI	-	IV2	IV3		EI
C22		-	IV4				-	VSI				-	IV3		
C23			-					-					-		
C24	IV4	VSI	EMI	-	EMI	IV3	IV3	EMI	-	EMI	IV3	IV3	EMI	-	EMI
C25		SI	SI		-	EI	IV3	SI		-	EI	IV2	SI		-

Table 6.15: Aggregated collective IF judgment matrices of 3 DMs' assessments

	C21			C22			C23			C24			C25		
	μ	v	∏	μ	v	∏	μ	v	∏	μ	v	∏	μ	v	∏
C21	0,020	0,180	0,800	0,220	0,280	0,500	0,528	0,211	0,261	0,187	0,565	0,248	0,034	0,196	0,770
C22	0,280	0,220	0,500	0,020	0,180	0,800	0,661	0,159	0,180	0,213	0,517	0,270	0,261	0,324	0,415
C23	0,213	0,517	0,270	0,170	0,618	0,211	0,020	0,180	0,800	0,000	1,000	0,000	0,270	0,330	0,400
C24	0,622	0,172	0,206	0,528	0,211	0,261	1,000	0,000	0,000	0,020	0,180	0,800	1,000	0,000	0,000
C25	0,098	0,123	0,779	0,348	0,259	0,393	0,330	0,270	0,400	0,000	1,000	0,000	0,020	0,180	0,800

***Step 6.3*: ** By using consistency value formula is adapted from the Abdullah & Najib (2014b) study, as given in Equation (6.17) and the random index (RI) is utilized from

Saaty (1996). For this example the consistency is calculated as 0,093 which means that the pairwise comparison is consistent.

<u>Step 6.4</u>**:** With the help of Equation (6.18) and (6.19) entropy weights of considered IF decision matrix of A is calculated as (0,192; 0,197; 0,187; 0,234; 0,190). The other pair-wise comparisons of other ANP values are calculated as the same way and because of space limitations, not all calculations are shown here.

<u>Step 6.5</u>**:** Form a supermatrix by entering the vectors obtained from IF-DEMATEL and IF-ANP evaluations into the appropriate column. In Table 6.16, the bold matrices are come from DEMATEL calculations and the rest is from IF-ANP. In this case, the supermatrix is raised to the power 20 and the weighted supermatrix results are given in Table 6.17.

Table 6.16: The initial supermatrix of GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS

	GOAL	**C11**	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C25**	**C31**	**C32**	**C33**	**C41**	**C42**
GOAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C11	0,233	**0,177**	**0,236**	**0,142**	**0,147**	**0,142**	0,188	0,196	0,192	0,228	0,186	0,175	0,182	0,183	0,192	0,188
C12	0,187	**0,220**	**0,313**	**0,129**	**0,205**	**0,142**	0,191	0,209	0,192	0,196	0,196	0,173	0,181	0,183	0,191	0,179
C13	0,195	**0,248**	**0,143**	**0,238**	**0,148**	**0,234**	0,191	0,192	0,190	0,192	0,195	0,218	0,224	0,198	0,185	0,222
C14	0,195	**0,153**	**0,161**	**0,185**	**0,246**	**0,181**	0,235	0,192	0,190	0,188	0,191	0,217	0,188	0,208	0,202	0,189
C15	0,190	**0,202**	**0,147**	**0,306**	**0,254**	**0,301**	0,195	0,211	0,236	0,196	0,232	0,217	0,225	0,228	0,230	0,222
C21	0,190	0,233	0,230	0,193	0,194	0,188	**0,280**	**0,183**	**0,193**	**0,226**	**0,238**	0,181	0,183	0,187	0,000	0,000
C22	0,192	0,192	0,200	0,203	0,192	0,195	**0,176**	**0,270**	**0,196**	**0,229**	**0,240**	0,184	0,182	0,184	0,000	0,000
C23	0,186	0,203	0,200	0,231	0,229	0,232	**0,207**	**0,182**	**0,281**	**0,185**	**0,201**	0,227	0,226	0,201	0,000	0,000
C24	0,231	0,186	0,185	0,188	0,184	0,186	**0,223**	**0,195**	**0,177**	**0,199**	**0,142**	0,181	0,183	0,198	0,000	0,000
C25	0,201	0,186	0,185	0,185	0,201	0,199	**0,114**	**0,170**	**0,153**	**0,161**	**0,179**	0,227	0,226	0,230	0,000	0,000
C31	0,333	0,283	0,333	0,358	0,283	0,296	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,334	0,333
C32	0,335	0,422	0,334	0,277	0,419	0,416	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,333	0,333
C33	0,332	0,295	0,333	0,365	0,298	0,288	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,333	0,334
C41	0,430	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,459	0,541	0,490	**0,298**	**0,425**
C42	0,570	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,541	0,459	0,510	**0,702**	**0,575**

Table 6.17: The weighted supermatrix results of RER selection

C11	**C12**	**C13**	**C14**	**C15**
0,073	0,077	0,079	0,077	0,089
C21	**C22**	**C23**	**C24**	**C25**
0,078	0,077	0,080	0,069	0,065
C31	**C32**	**C33**	**C41**	**C42**
0,051	0,056	0,051	0,037	0,042

The results shows that C15 (Technology Maturity / Innovation) rank as the first and the rest is C23 (Technology / Know-How Cost) and C13 (Resource Availability).

***Step 7*:** Application of IF-TOPSIS steps. The preliminary information comes from the IF-DEMATEL and IF-ANP steps.

Step 7.1: The evaluations for each of three alternatives are shown in Table 6.18. Using Equation (6.7) aggregation process is done. As an example the aggregated IF decision matrix of Wind (A1) is presented in Table 6.19.

Table 6.18: Linguistic evaluation data of alternatives with respect to sub-criteria

	Wind			Solar			Biogas			Hydro			Geothermal		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C11	U	SU	U	MI	SI	SI	EI	EI	EI	I	I	I	VI	EI	EI
C12	VI	VI	EI	VI	EI	EI	VI	VI	VI	VI	VI	I	EI	EI	EI
C13	VI	EI	EI	EI	VI	EI	I	I	SI	SI	I	VI	EI	EI	EI
C14	VU	U	U	EU	VU	EU	EU	EU	EU	EI	EI	EI	SU	MI	MI
C15	VI	EI	VI	I	I	VI	VI	I	I	EI	EI	EI	EI	VI	VI
C21	I	VI	I	SI	MI	MI	I	I	SI	EI	EI	EI	SU	MI	SU
C22	VI	EI	EI	EI	VI	EI	I	I	I	VI	VI	VI	VI	VI	VI
C23	EI	VI	EI	VI	EI	VI	MI	MI	SI	EI	EI	EI	I	I	VI
C24	VI	VI	I	VI	I	I	VI	I	I	EI	EI	EI	I	VI	VI
C25	I	I	SI	U	U	SU	U	U	U	VI	EI	VI	SU	MI	SU
C31	SI	I	I	VI	VI	VI	VI	EI	VI	EI	VI	I	VI	EI	VI
C32	MI	SI	MI	SI	MI	MI	VI	I	I	I	VI	I	SI	I	I
C33	VI	VI	EI	EI	EI	EI	VI	EI	EI	U	VU	VU	I	I	VI
C41	VI	I	I	I	I	VI	EI	EI	EI	I	I	VI	SI	I	SI
C42	I	I	VI	SI	MI	MI	EI	EI	EI	I	SI	SI	EI	EI	EI

***Step 7.2*:** Equations (6.20)-(6.24) are utilized to find the negative and positive ideal solutions.

***Step 7.3*:** Determine the most appropriate alternative by CC_i values of intuitionistic ideal solution. Table 6.20 summarized the final ranking for each alternative.

Table 6.19: Aggregated IF decision matrix of A1

	μ	v	∏
C11	0,063	0,910	0,028
C12	0,000	0,952	0,048
C13	0,048	0,900	0,053
C14	0,003	0,990	0,008
C15	0,000	0,952	0,048
C21	0,000	0,960	0,040
C22	0,000	0,950	0,050
C23	0,000	0,950	0,050
C24	0,450	0,477	0,072
C25	0,000	0,960	0,040
C31	0,300	0,640	0,060
C32	0,025	0,945	0,030
C33	0,000	0,952	0,048
C41	0,000	0,960	0,040
C42	0,675	0,240	0,085

Table 6.20: Separation measures and CCi of each alternative

Alternatives	**S^+**	**S^-**	**CC_i**
Wind	0,577	0,458	0,446
Solar	0,792	0,233	0,256
Biogas	0,260	0,765	0,787
Hydro	0,582	0,708	0,572
Geothermal	0,128	0,925	**0,853**

The alternative Geothermal Energy is preferred as the most eligible alternative since it has the greatest CCi value of (0,853) among all other alternatives. According to Table 6.20 the scores of the alternatives are 0,853; 0,787; 0,572; 0,446 and 0,256 and the rank of the alternatives best to worst is Geothermal, Biogas, Hydro, Wind and Solar.

6.5 Analysis of Obtained Results

The developed evaluation framework can help investors and researchers in reaching useful judgements and gaining research insights. Obtaining influential weights with DEMATEL the impact - diagraph map for the total relations are drawn. Economic Aspects are given in Figure 6.2. According to Table 6.11; C23, C24 and C25 are receivers; C21 and C22 are dispatchers. From calculations it is seen that C21 (Investment Cost) has the value of (D_{21}– R_{21}= 0,900) and is regarded as an important cause.

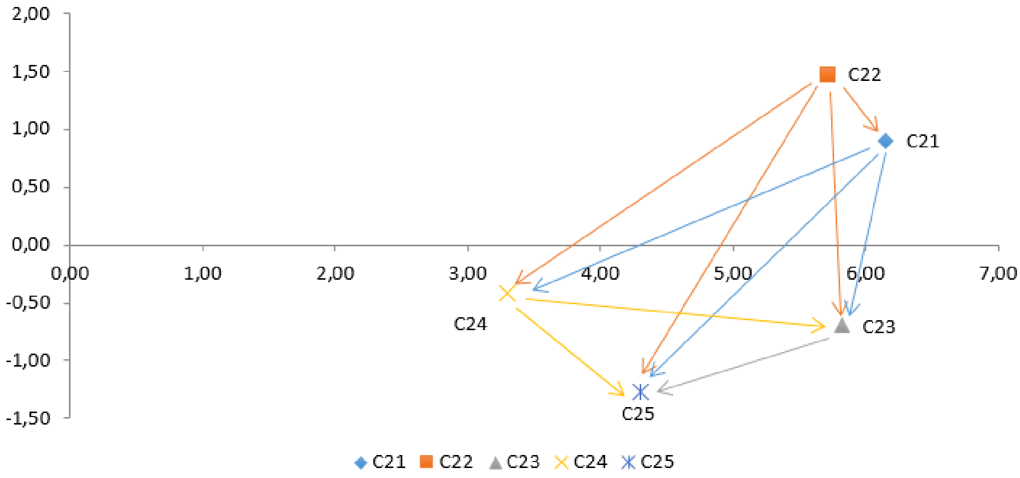

Figure 6.2: The impact-diagraph map of the total relations for Economic Aspects

C22 (Operation and Maintenance Cost) is regarded also as an important cause it influences all the others with a high importance of (D_{22}+ R_{22}= 5,710). Therefore, investors should focus on Investment Cost and Operation and Maintenance Costs.

Total relation matrix of Technical Aspects is given and the impact-diagraph map is presented in Figure 6.3. The results indicate that C13 and C15 are dispatchers; C11, C12 and C14 are receivers.

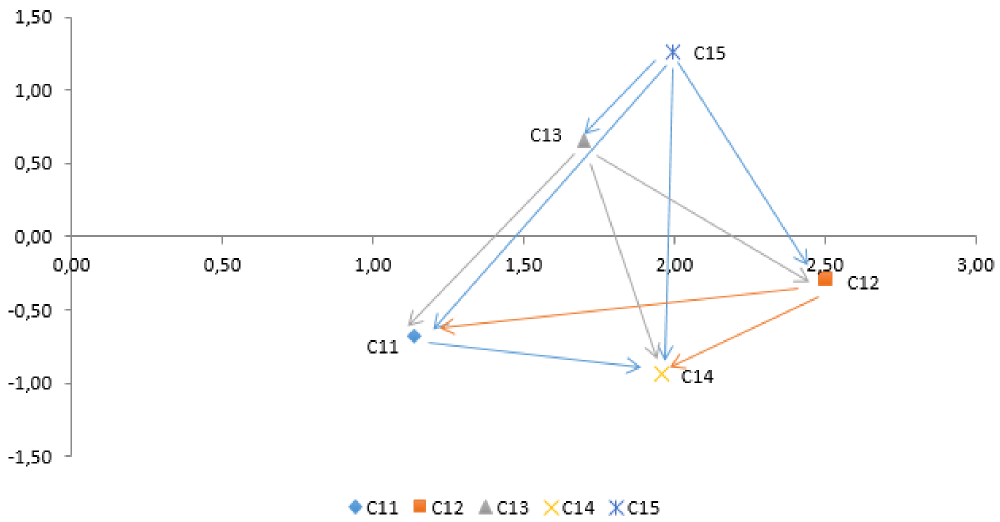

Figure 6.3: The impact-diagraph map of the total relations for Technical Aspects

It is seen that C15 (Technology Maturity / Innovation) has the value of ($D_{15} - R_{15}$= 1,270) and is regarded as an important cause as it influences all the others with a high importance ($D_{15} + R_{15}$= 1,997). C13 (Resource Availability) has ($D_{13} - R_{13}$= 0,655) and is in cause group. Therefore, investors should focus on Technology Maturity / Innovation and Resource Availibilty.

Figure 6.4 shows the Environmental Aspects impact-diagraph. Here, C41 (Green House Emissions) is dispatcher and C42 (Land Use / Requirement) is receiver. According to Figure 6.4, it is seen that C41 is in an important cause as it influences the other criteria.

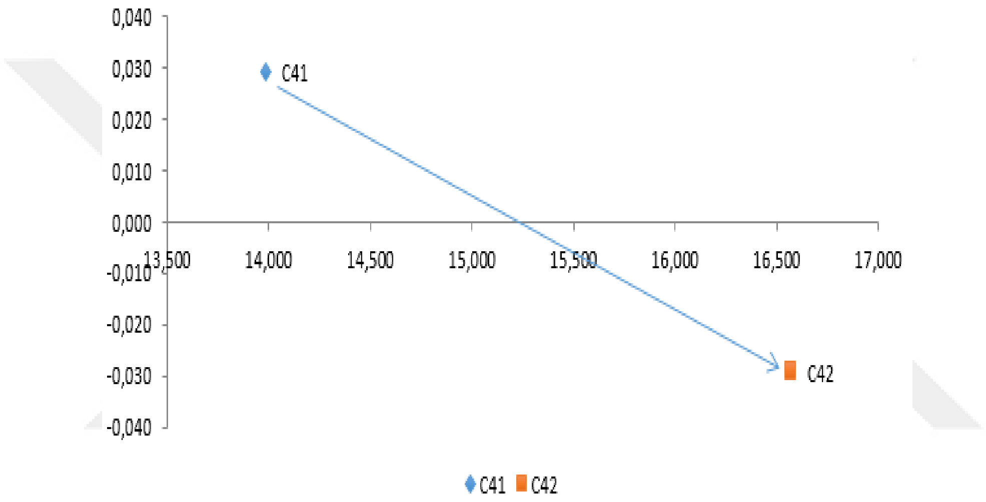

Figure 6.4: The impact-diagraph map of the total relations for Environmental Aspects

Once the relationships between sub-criteria by DEMATEL have been analyzed, then criteria weights are calculated with ANP and results are given in Table 6.17. According to calculated final weights, Technical Aspects has a weight of 0,395; Economic Aspects has a weight of 0,368; Political - Social Aspects has a weight of 0,158 and Environmental Aspects has a weight of 0,079. It is seen that the most important criterion is Technical Aspects. It is followed by Economic Aspects > Political - Social Aspects > Environmental Aspects. Once the weights of the criteria have been obtained, DMs compare the alternatives with respect to each criterion with TOPSIS. Table 5.12 indicates that investors should invest Geothermal energy and the remaining alternatives are ranked as Biogas > Hydro > Wind > Solar.

7. DISCUSSIONS

In this study three different approaches for RER selection is proposed. This section presents Comparative and Sensitivity Analysis. Firstly, Comparative Analysis is conducted to monitor the changes of the ranking in different approaches, then Sensitivity Analysis is applied to observe the effects of possible changes in weights to the application results.

7.1 Comparative Analysis

At the application steps, three approaches applied for obtaining ranking list of RER alternatives from investor perspectives. Application 1 consists of GDM based integrated DEMATEL, ANP and TOPSIS with crisp numbers; Application 2 consists of GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS and Application 3 consists of GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS. The alternatives are ranked in descending order according to their CCi values, and the results are given in Table 7.1 and Figure 7.1.

Table 7.1: Comparison results for the final ranking of alternatives

RER alternatives	Application 1 DEMATEL, ANP and TOPSIS	Ranking	Application 2 Linguistic interval fuzzy DEMATEL, ANP and TOPSIS	Ranking	Application 3 IF-DEMATEL IF-ANP and IF-TOPSIS	Ranking
Wind	0,473	2	0,457	3	0,446	4
Solar	0,309	4	0,262	5	0,256	5
Biogas	0,252	5	0,328	4	0,787	2
Hydro	0,773	1	0,811	1	0,572	3
Geothermal	0,458	3	0,494	2	0,853	1

It is seen that the ranking is found as the following: Application 1: Hydro > Wind > Geothermal > Solar > Biogas; Application 2: Hydro > Geothermal > Wind > Biogas > Solar; Application 3: Geothermal > Biogas > Hydro > Wind > Solar. This indicates that for two applications Hydro energy remains to be the best alternative, however, in Application 3 Geothermal energy ranks as the most appropriate alternative among others.

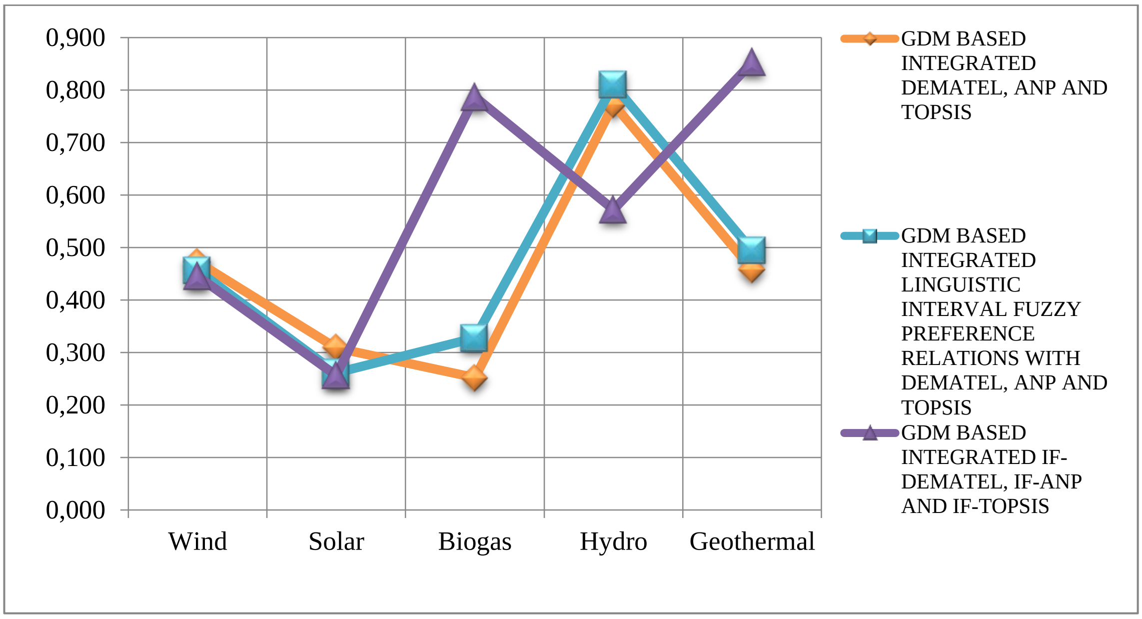

Figure 7.1: Comparative Analysis results of three applications

By taking into account the comparison as stated, the ranking of alternatives is changed. This may be because fuzziness and uncertainties in linguistic environment are characterized more comprehensively, and in IF environment both the membership as well as the non-membership degrees are used (Atanassov, 1986). When compared with conventional fuzzy sets, IFSs provide a more extensive tool for considering imprecision. The results indicates a different perspective to the RER selection problem in Turkey. Unlike many other papers, in application 3 it is found that the most appropriate RER for Turkey is power generation from geothermal sources, followed by biogas. This finding can be associated with legal difficulties for getting permits for wind farms in Turkey in recent years (Büyüközkan & Güleryüz, 2017).

7.2 Sensitivity Analysis

To observe the effects of the possible changes in the weights of the sub-criteria on the RER selection decision, sensitivity analyses are conducted for three approaches. The five different cases are given to see if changes in weights affected the ranking of alternatives or not. For three applications, Sensitivity Analysis performed in the following sub sections.

7.2.1 Sensitivity Analysis for Application 1

Firstly for, GDM Based Integrated DEMATEL, ANP and TOPSIS sensitivity analysis is done with calculated weights in Table 7.2.

Table 7.2: Sensitivity analysis by changing C15

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
C11	0,029	0,035	0,030	0,018	0,005	0,001
C12	0,080	0,094	0,083	0,049	0,014	0,002
C13	0,071	0,083	0,073	0,043	0,013	0,001
C14	0,066	0,077	0,068	0,040	0,012	0,001
C15	**0,149**	**0,000**	**0,250**	**0,500**	**0,750**	**0,900**
C21	0,084	0,099	0,087	0,051	0,015	0,002
C22	0,082	0,096	0,085	0,050	0,015	0,002
C23	0,119	0,140	0,123	0,072	0,021	0,002
C24	0,029	0,034	0,030	0,018	0,005	0,001
C25	0,055	0,065	0,057	0,033	0,010	0,001
C31	0,060	0,070	0,062	0,036	0,011	0,001
C32	0,063	0,074	0,066	0,039	0,011	0,001
C33	0,035	0,041	0,036	0,021	0,006	0,001
C41	0,035	0,041	0,036	0,021	0,006	0,001
C42	0,044	0,051	0,045	0,027	0,008	0,001

In this analysis, Case 0 is the current case. In Scenario 1, C15 (Technology Maturity / Innovation) is selected because it has the largest weight with respect to other sub-criteria. As an example in Case 0, weights of C15 changed from 0,149 to 0 in Case 1 and the weights of other sub-criteria modified proportionally.

The calculated weights are added to the associated matrices in GDM Based Integrated DEMATEL, ANP and TOPSIS. The sensitivity results of ranking alternatives are shown in Figure 7.2 and Table 7.3. Here, X axis represents the cases while Y axis represents the scores of alternatives.

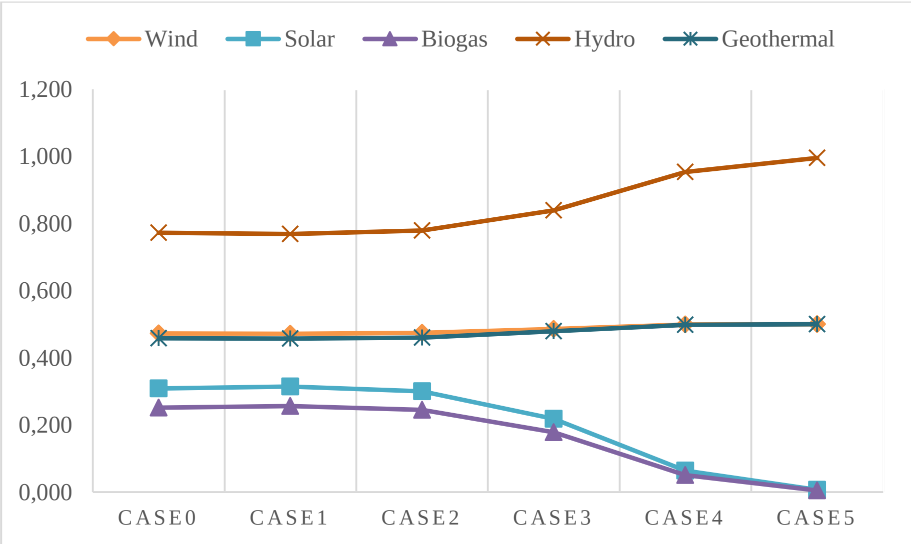

Figure 7.2: Ranking of RER alternatives in Scenario 1

Table 7.3: Ranking results of RER alternatives in Scenario 1

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Wind	0,473	0,472	0,474	0,486	0,499	0,500
Solar	0,309	0,315	0,300	0,218	0,064	0,007
Biogas	0,252	0,257	0,245	0,178	0,051	0,005
Hydro	0,773	0,769	0,779	0,839	0,954	0,995
Geothermal	0,458	0,457	0,461	0,479	0,498	0,500

By changing C15 it is seen in Figure 7.2 that, the weights of criteria slightly changes but the ranking of alternatives remains same.

In Scenario 2, C31 (Compatibility with Legal Compliance) is selected because it has a median weight with respect to other sub-criteria. Here Sensitivity Analysis is done with calculated weights in Table 7.4.

Table 7.4: Sensitivity Analysis by changing C31

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
C11	0,029	0,031	0,025	0,013	0,004	0,000
C12	0,080	0,085	0,068	0,036	0,010	0,001
C13	0,071	0,075	0,060	0,032	0,009	0,001
C14	0,066	0,070	0,056	0,030	0,008	0,001
C15	0,149	0,158	0,126	0,067	0,018	0,002
C21	0,084	0,089	0,071	0,038	0,010	0,001
C22	0,082	0,087	0,069	0,037	0,010	0,001
C23	0,119	0,126	0,101	0,054	0,014	0,002
C24	0,029	0,031	0,025	0,013	0,004	0,000
C25	0,055	0,058	0,047	0,025	0,007	0,001
C31	**0,060**	**0,000**	**0,250**	**0,500**	**0,750**	**0,900**
C32	0,063	0,067	0,054	0,029	0,008	0,001
C33	0,035	0,037	0,029	0,016	0,004	0,000
C41	0,035	0,037	0,030	0,016	0,004	0,000
C42	0,044	0,047	0,037	0,020	0,005	0,001

The calculated weights are added to the associated matrices in GDM Based Integrated DEMATEL, ANP and TOPSIS. The sensitivity results of ranking alternatives are shown in Figure 7.3 and Table 7.5.

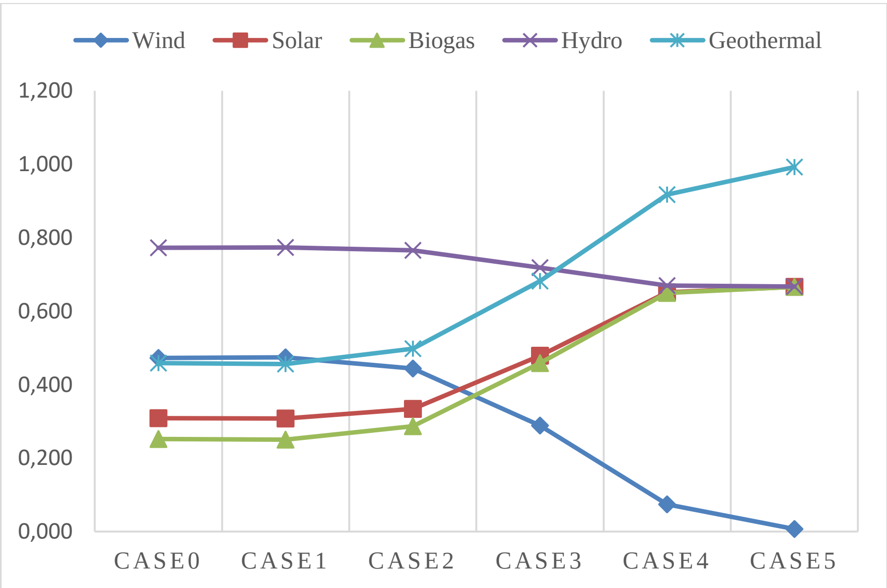

Figure 7.3: Ranking of RER alternatives in Scenario 2

Table 7.5: Ranking results of RER alternatives in Scenario 2

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Wind	0,473	0,474	0,444	0,288	0,074	0,007
Solar	0,309	0,308	0,334	0,478	0,651	0,667
Biogas	0,252	0,250	0,287	0,459	0,650	0,667
Hydro	0,773	0,773	0,766	0,719	0,670	0,667
Geothermal	0,458	0,456	0,498	0,682	0,918	0,992

These findings shows that the ranking of alternatives changes in different cases. After Case 2, the separation between Geothermal and Wind starts to become visible and this differentiation effects Geothermal in a positive way. On the other hand Wind energy encounters a big drop by the rise of C31. In Cases 1, 2 and 3 Hydro energy ranks as first alternative but in Case 4 and 5 Geothermal energy ranks at first.

7.2.2 Sensitivity Analysis for Application 2

Secondly for GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS, sensitivity analysis is done. In Scenario 1 in given Table 7.6, C21 (Investment cost) is selected because it has the largest weight with respect to other sub-criteria.

Table 7.6: Sensitivity Analysis by changing C21

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
C11	0,081	0,092	0,069	0,046	0,023	0,009
C12	0,056	0,062	0,047	0,031	0,016	0,006
C13	0,075	0,084	0,063	0,042	0,021	0,008
C14	0,073	0,082	0,061	0,041	0,020	0,008
C15	0,110	0,124	0,093	0,062	0,031	0,012
C21	**0,110**	**0,000**	**0,250**	**0,500**	**0,750**	**0,900**
C22	0,054	0,061	0,046	0,031	0,015	0,006
C23	0,099	0,112	0,084	0,056	0,028	0,011
C24	0,033	0,037	0,028	0,019	0,009	0,004
C25	0,071	0,080	0,060	0,040	0,020	0,008
C31	0,050	0,056	0,042	0,028	0,014	0,006
C32	0,082	0,092	0,069	0,046	0,023	0,009
C33	0,027	0,030	0,023	0,015	0,008	0,003
C41	0,038	0,043	0,032	0,021	0,011	0,004
C42	0,041	0,046	0,035	0,023	0,012	0,005

In this analysis Case 0 is the current case. The calculated weights are added to the associated matrices in GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS. The sensitivity results of ranking alternatives are shown in Table 7.7 and Figure 7.4.

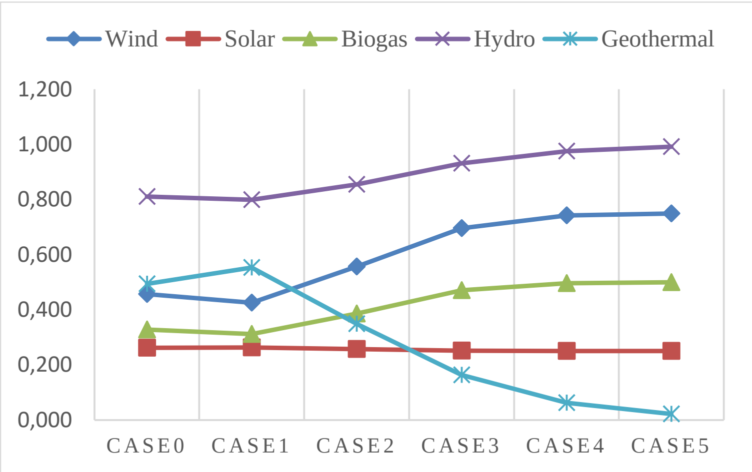

Figure 7.4: Ranking of RER alternatives in Scenario1

Table 7.7: Ranking results of RER alternatives in Scenario 1

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Wind	0,457	0,426	0,557	0,696	0,742	0,749
Solar	0,262	0,263	0,258	0,252	0,250	0,250
Biogas	0,328	0,312	0,386	0,471	0,496	0,500
Hydro	0,811	0,799	0,854	0,931	0,975	0,991
Geothermal	0,494	0,553	0,349	0,164	0,062	0,022

According to both cases, Hydro is the best option among all cases. But in the following, such as in Case 2 Wind becomes the second alternative and for the remaining Geothermal ranks as the last one. The most noticeable change includes Geothermal energy and Wind energy ranking in these cases.

In Scenario 2, C25 (Revenue / Financial Structure) is selected because it has a median weight with respect to other sub-criteria. Here sensitivity analysis is done with calculated weights in Table 7.8. The calculated weights are added to the associated matrices and the sensitivity results of ranking alternatives are Table 7.9 and Figure 7.5.

Table 7.8: Sensitivity Analysis by changing C25

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
C11	0,081	0,088	0,066	0,044	0,022	0,009
C12	0,056	0,060	0,045	0,030	0,015	0,006
C13	0,075	0,081	0,060	0,040	0,020	0,008
C14	0,073	0,078	0,059	0,039	0,020	0,008
C15	0,110	0,118	0,089	0,059	0,030	0,012
C21	0,110	0,119	0,089	0,059	0,030	0,012
C22	0,054	0,059	0,044	0,029	0,015	0,006
C23	0,099	0,107	0,080	0,054	0,027	0,011
C24	0,033	0,036	0,027	0,018	0,009	0,004
C25	**0,071**	**0,000**	**0,250**	**0,500**	**0,750**	**0,900**
C31	0,050	0,053	0,040	0,027	0,013	0,005
C32	0,082	0,088	0,066	0,044	0,022	0,009
C33	0,027	0,029	0,022	0,014	0,007	0,003
C41	0,038	0,041	0,031	0,020	0,010	0,004
C42	0,041	0,044	0,033	0,022	0,011	0,004

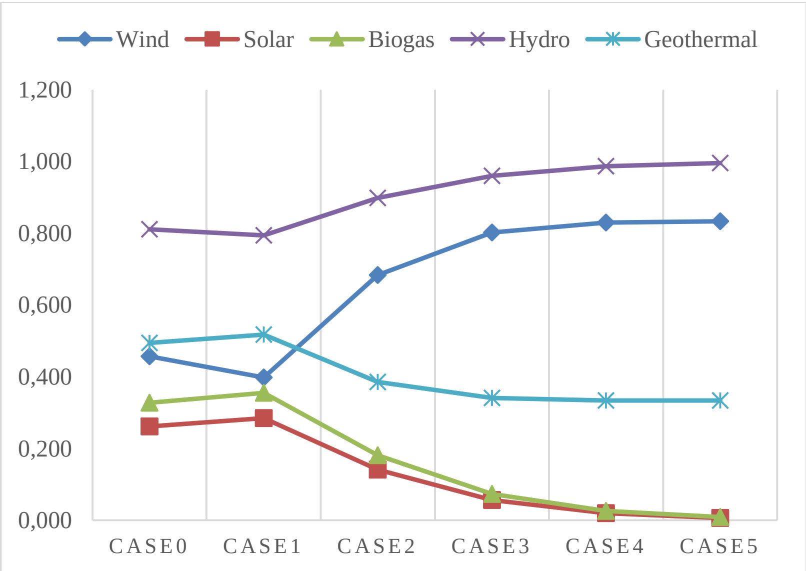

Figure 7.5: Ranking of RER alternatives in Scenario 2

According to both cases, Hydro energy is the best option by a small increase between cases. Solar and Biogas energies have dramatic decreases in most cases. Wind and Geothermal energies have opposing behavior by the change of C25. Therefore, C25 effects the other criteria with a big impact.

Table 7.9: Ranking results of RER alternatives in Scenario 2

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Wind	0,457	0,398	0,683	0,802	0,829	0,833
Solar	0,262	0,285	0,141	0,056	0,020	0,007
Biogas	0,328	0,355	0,181	0,074	0,026	0,009
Hydro	0,811	0,794	0,898	0,960	0,986	0,995
Geothermal	0,494	0,518	0,386	0,341	0,334	0,333

In Scenario 3, C33 (Social Acceptability) is selected. Here sensitivity analysis is done with calculated weights in Table 7.10. The results of ranking alternatives are shown in Figure 7.6 and Table 7.11.

Table 7.10: Sensitivity Analysis by changing C33

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
C11	0,081	0,084	0,063	0,042	0,021	0,008
C12	0,056	0,057	0,043	0,029	0,014	0,006
C13	0,075	0,077	0,058	0,038	0,019	0,008
C14	0,073	0,075	0,056	0,037	0,019	0,007
C15	0,110	0,113	0,085	0,057	0,028	0,011
C21	0,110	0,113	0,085	0,057	0,028	0,011
C22	0,054	0,056	0,042	0,028	0,014	0,006
C23	0,099	0,102	0,077	0,051	0,026	0,010
C24	0,033	0,034	0,025	0,017	0,008	0,003
C25	0,071	0,073	0,055	0,037	0,018	0,007
C31	0,050	0,051	0,038	0,025	0,013	0,005
C32	0,082	0,084	0,063	0,042	0,021	0,008
C33	**0,027**	**0,000**	**0,250**	**0,500**	**0,750**	**0,900**
C41	0,038	0,039	0,029	0,020	0,010	0,004
C42	0,041	0,042	0,032	0,021	0,011	0,004

Hydro energy ends up drastically low after increasing criteria C33 value to 0,900. The other alternatives Wind, Geothermal, Solar and Biogas energies are affected in a positive way. Solar and Biogas share the last position in case 0 however by the end of case 5 they get the highest ranking together.

Table 7.11: Ranking results of RER alternatives in Scenario 3

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Wind	0,457	0,453	0,654	0,789	0,827	0,833
Solar	0,262	0,248	0,619	0,827	0,935	0,977
Biogas	0,328	0,319	0,629	0,831	0,936	0,978
Hydro	0,811	0,835	0,397	0,181	0,069	0,024
Geothermal	0,494	0,491	0,677	0,797	0,829	0,833

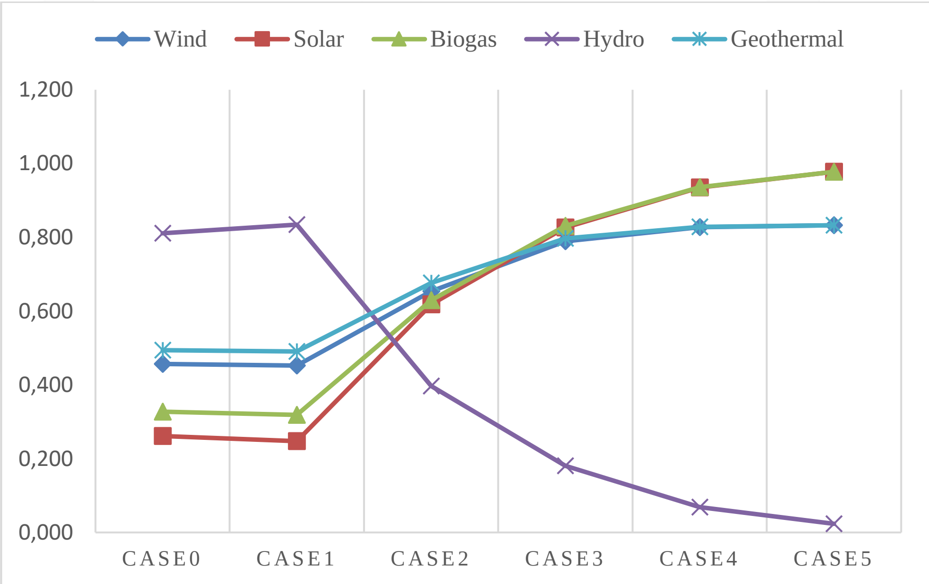

Figure 7.6: Ranking of RER alternatives in Scenario 3

7.2.3 Sensitivity Analysis for Application 3

GDM Based Integrated IF DEMATEL, IF-ANP and IF-TOPSIS sensitivity analysis is conducted. In this study, three scenarios are presented. Because of being intuitionistic numbers, assesments of DMs evalautions are changed.

In scenario 1, C25 (Revenue / Financial Structure) is choosen because it has a medium weight with respect to other sub-criteria.The five different cases are given in Figure 7.7 and Case 0 is the current case of the problem.The results of ranking alternatives are shown in Table 7.12 and Figure 7.8. These findings shows that the ranking of alternatives changes especially in Case 1, 2, 3 and 4 Geothermal ranks as first alternative but in Case 4 and 5 Hydro energy shows radical changes and ranks as first alternative.

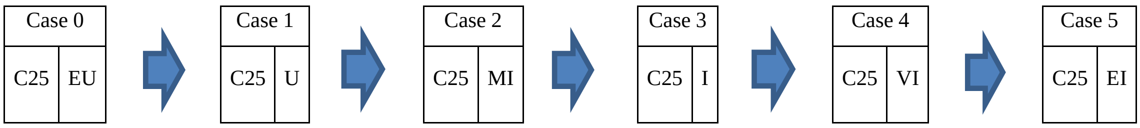

Figure 7.7: Cases of assesments in Scenerio 1

Table 7.12: Ranking of alternatives in different cases of Scenario 1

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Wind	0,446	0,481	0,507	0,527	0,537	0,540
Solar	0,256	0,234	0,214	0,198	0,191	0,188
Biogas	0,787	0,684	0,595	0,526	0,491	0,481
Hydro	0,572	0,600	0,620	0,635	0,643	0,645
Geothermal	0,853	0,779	0,715	0,665	0,640	0,633

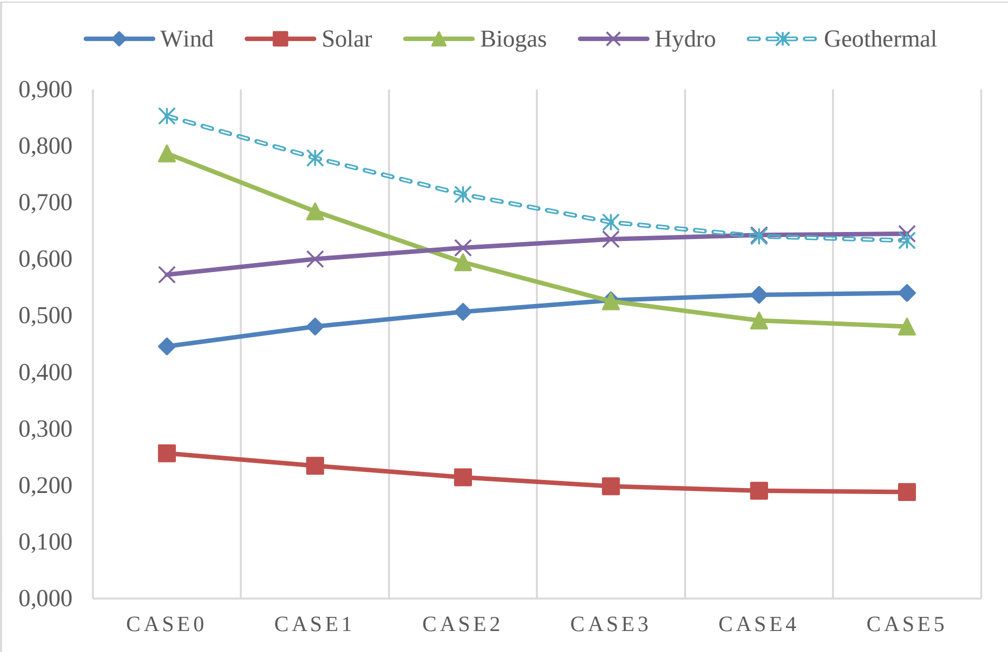

Figure 7.8: Ranking of RER alternatives in Scenario 1

In scenario 2, C15 (Technology Maturity / Innovation) is choosen because it has the largest weight with respect to other sub-criteria.The five different cases are given in Figure 7.9 and Case 0 is the current case of the problem.

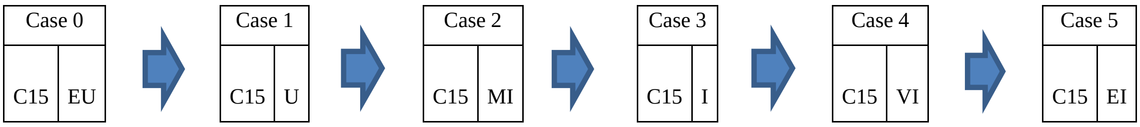

Figure 7.9: Cases of assesments in Scenerio 2

The results of ranking alternatives are shown in Table 7.13 and Figure 7.10. These findings shows that the ranking of alternatives in different cases remain same and Geothermal is the most appropriate alternative among different cases. The differences in the values may come from the assessment of experts.

Table 7.13: Ranking of alternatives in different cases of Scenario 2

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Wind	0,446	0,460	0,473	0,485	0,492	0,494
Solar	0,256	0,248	0,241	0,233	0,229	0,228
Biogas	0,787	0,763	0,740	0,718	0,705	0,701
Hydro	0,572	0,583	0,593	0,603	0,609	0,611
Geothermal	0,853	0,852	0,850	0,849	0,848	0,848

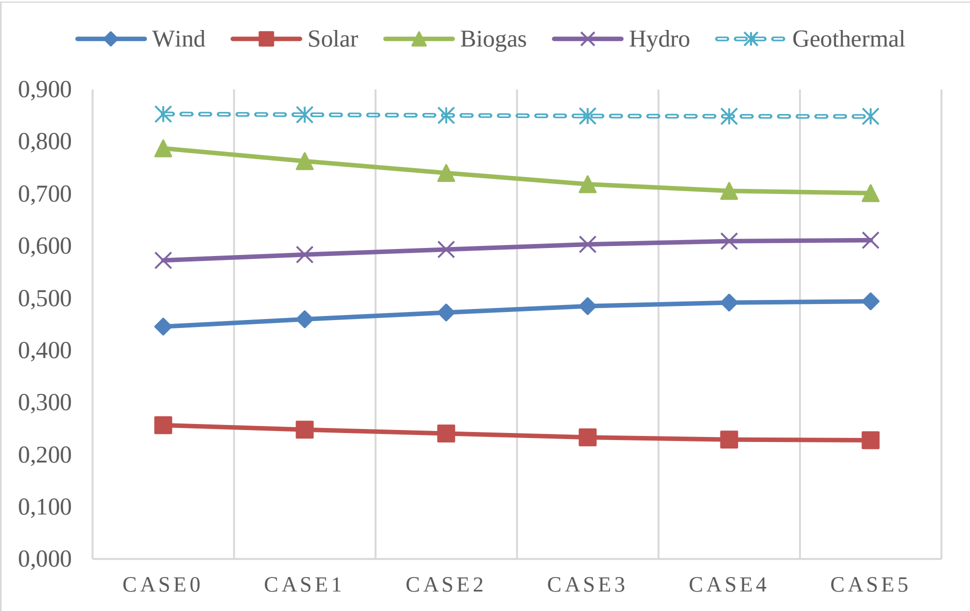

Figure 7.10: Ranking of RER alternatives in Scenario 2

In scenario 3 C41 (Greenhouse Emissions) is choosen because it has the lowest weight with respect to other sub-criteria.The five different cases are given in Figure 7.11.

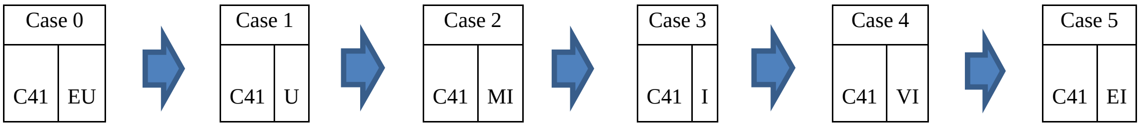

Figure 7.11: Cases of assesments in Scenario 3

The results of ranking alternatives are shown in Table 7.14 and Figure 7.12.

Table 7.14: Ranking of alternatives in different cases of Scenario 3

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Wind	0,446	0,455	0,462	0,469	0,473	0,474
Solar	0,256	0,278	0,297	0,313	0,322	0,325
Biogas	0,787	0,802	0,815	0,826	0,832	0,834
Hydro	0,572	0,572	0,571	0,571	0,570	0,570
Geothermal	0,853	0,795	0,744	0,699	0,675	0,667

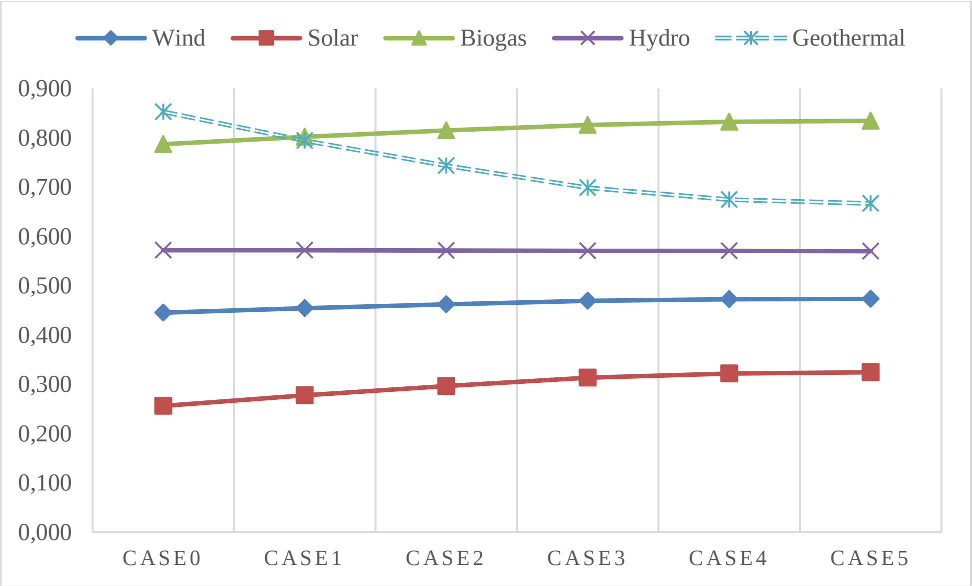

Figure 7.12: Ranking of RER alternatives in Scenario 3

These findings shows that the ranking of alternatives in different cases changes. As an example in Case 1 slight changes in DMs assessments Biogas energy to be the first alternative in all cases.

8. CONCLUSIONS AND PERSPECTIVES

In accordance with the available RER potential in Turkey, high rate of RER utilization is possible. However, a very limited portion of the available potential is currently in use. The eastern part of Turkey has significant hydro energy potential, whereas the western part has high wind and geothermal energy potential. In addition, the southern and southeastern parts have plentiful solar energy. Turkey is known to be rich in terms RER and selection of these resources requires a careful plan during the decision making processes.

The objective of the thesis was to select the most appropriate RER alternative for Turkey from investor perspective. To achieve this purpose, there was a need for an effective RER selection model with well-balanced, robust approach. In this thesis, based on the information gathered from detailed literature survey (scientific journals, research papers, and several published investment project reports) and DMs' views, a new evaluation model was developed. This proposed RER evaluation model differentiates itself from the literature with its investor perspective.

Three MCDM approaches were utilized in the thesis. Firstly, GDM based integrated DEMATEL, ANP and TOPSIS approach with crisp numbers was applied. Secondly, a new GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS approach was proposed. Thirdly, a new GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS approach was developed. Three applications with these analytic approaches were carried out in order to validate how effective the proposed evaluation model performs. This thesis furthermore presents, Comparative Analysis to compare the outcomes of the analytical approaches.

According to the results of first two approaches (Applications 1 and 2), Hydro energy takes the first place, and for the third approach (Application 3) Geothermal energy takes the highest score among other alternatives. Because of the view that uncertainty is evaluated more comprehensively with hesitancy degree in IF environment, the obtained results are different.

In summary, this thesis has scientific value in the following contributions:

- The originality of the thesis comes from the proposition of an effective and comprehensive evaluation model for both Turkey and literature and its application to RER selection problem from investor perspective with GDM based integrated DEMATEL, ANP and TOPSIS approach. DEMATEL is adopted for determining the relationships of criteria whereas ANP is applied to find criteria weights. Additionally, TOPSIS is used for ranking RER alternatives.
- The other originality of the thesis comes from the proposition of GDM based integrated linguistic interval fuzzy preference relations with DEMATEL, ANP and TOPSIS for the first time in literature.
- Another contribution of the thesis is the proposition of the GDM based integrated IF-DEMATEL, IF-ANP and IF-TOPSIS approach. No previous work has investigated RER selection using this kind of an integrated method.

The proposed evaluation model and the applied analytical technics can help practitioners to improve their decision making process, especially when criteria are numerous and related. Besides, to cope with eliminating vagueness and uncertainty, the proposed integrated methodologies ensures a more precise description of decision making process.

For future research, a more automatic algorithm and a Decision Support System (DSS) tool can be adopted in order to facilitate the computational tasks. The proposed integrated approaches can be used for tackling similar decision making problems in the field of energy or other industries. Another probable research subject may be RER selection with other MCDM techniques and how they can be compared with their application results. Moreover, Dempster Shafer Theory may be applied to the proposed IFS based integrated approach and wherein the results can be compared with the obtained results.

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BIOGRAPHICAL SKETCH

Sezin Güleryüz was born in Istanbul. She received her B.Sc. degree in industrial engineering from Kadir Has University in honor list in 2008. Also, she received the other B.Sc. degree in Anadolu University in management at the same year. She received M.Sc. degree in industrial engineering from Yıldız Technical University in 2010. She is now a Ph.D. student in industrial engineering department and research assistant at Galatasaray University with a special program. Her current studies mainly focus on multi-criteria decision making, renewable energy, supply chain management, and the application of fuzzy sets theory on these areas.

Thesis Publications

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