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SUSTAINABLE AND RENEWABLE ENERGY POWER PLANTS EVALUATION BY FUZZY VIKOR AND FUZZY TODIM TECHNIQUES

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SUSTAINABLE AND RENEWABLE ENERGY POWER PLANTS EVALUATION BY FUZZY VIKOR AND FUZZY TODIM TECHNIQUES

(SÜRDÜRÜLEBİLİR VE YENİLENEBİLİR ENERJİ SANTRALLERİNİN BULANIK VIKOR VE BULANIK TODIM TEKNİKLERİYLE DEĞERLENDİRİLMESİ)

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LIST OF SYMBOLS

AHP	: Analytical Hierarchy Process
ANP	: Analytical Network Process
CO_2	: Carbon Dioxide
CO_2 –eq	: Carbon Dioxide equivalent
ÇÖKV	: Çok ölçütlü karar verme sistemleri
DEMATEL	: Decision Making Trial and Evaluation Laboratory
ELECTRE	: Elimination and Choice Expressing the Reality
FMCDM	: Fuzzy Multi Criteria Decision Making
GAP	: South Eastern Anatolia Project (English)
GHG	: Green House Gas
GW	: Gigawatt
HE	: Hydraulic Energy
kWh	: Kilowatt Hour
LFG	: Landfill Gas
LFG-E	: Landfill Gas Energy
MCDM	: Multi Criteria Decision Making
MW	: Megawatt
MWh	: Megawatt Hour
PROMETHEE	: Preference Ranking Organization Method for Enrichment Evaluation
RE	: Renewable Energy
REPA	: Wind Energy Potential Map (English)
SE	: Solar Energy
TFN	: Triangular Fuzzy Number
TODIM	: Interactive and Multicriteria Decision Making (English)
TOPSIS	:Technique for Order Preference by Similarity to Ideal Solution
VIKOR	: Multicriteria Optimization and Compromise Solution (English)
WE	: Wind Energ

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ABSTRACT

Sustainable and renewable energy systems are an effective solution to depletion of fossil energy resources and prevent serious environmental problems resulted from energy production. The government of Turkey is aware of current global warming issue and puts emphasize on growing renewable energy utilization rate in meeting energy demand of the country. Moreover, Turkey has prepared a comprehensive plan in every field for 2023, which is the year of its hundredth anniversary. Energy plan is to increase the share of renewable energy in the electricity generation of the country above thirty percent. In order to achieve the objective, the government encourages investors economically to invest in renewable energy field. Therefore, in this study, we aimed to find out the best performing energy alternative and thus to guide decision makers on energy investments. We evaluated four sustainable and renewable energy power plant types, which are solar, wind hydraulic and landfilled gas (LFG). For the evaluation of the alternatives, there are many factors to consider and multicriteria decision making (MCDM) methods are an appropriate approach to this issue. In this regard, we determined 22 evaluation criteria in technical, economical and environmental aspects. Combination of three aspects makes the evaluation process more comprehensive. We conducted this study with two different MCDM technics VIKOR and TODIM, and compared the results. In general, a typical MCDM method ranks the alternatives regarding specified criteria. Apart from this, TODIM considers risk factor while ranking operation. This feature of TODIM results from prospect theory. Besides, VIKOR is a strength MCDM technic that provides a compromise solution and we wanted to support the evaluation process by adding risk factor with TODIM technic. Additionally, in order to cope with vagueness and uncertainty in the evaluation process, we integrated fuzzy approach into VIKOR and TODIM methods. Finally, according to VIKOR application results LFG is best performing sustainable energy resource followed by solar, wind and hydraulic. In TODIM results we have two different ranking lists. When attenuation

factor of loss θ equals to 1 and 2.5, solar energy emerged as the best option and it is followed by LFG energy, wind, and hydraulic energy respectively. In the other scenario when θ equals to 3 and 4, solar and LFG energy ranks interchanged and LFG energy placed in the first order, solar energy is in the second order. Ranks of wind and hydraulic energy stayed same.

ÖZET

Sürdürülebilir ve yenilenebilir enerji kaynakları fosil enerji kaynaklarının azalmasında ve enerji üretiminden kaynaklanan ciddi çevresel problemlerin önlenmesinde etkili bir çözümdür. Türkiye bir ülke olarak küresel ısınma sorununun bilincindedir ve kendi enerji ihtiyacının karşılanmasında yenilenebilir enerji kaynaklarının payının artmasına önem vermektedir. Bunun yanısıra Türkiye 2023 100. kuruluş yılına ithafen, her alanda gelişmeler öngören kapsamlı bir kalkınma planı hazırlamıştır. Bu plana göre enerji alanındaki hedef elektrik üretimindeki yenilenebilir enerji payını %30 un üzerine çıkarmaktır. Devlet bu hedefini gerçekleştirmek için teşvik politikası uygulamakta, yatırımcıları bu alanda yatırım yaptıkları zaman ekonomik olarak desteklemektedir. Yapılan bu çalışmada, en iyi performans gösteren enerji çeşidini bulmak ve bu sayede enerji yatırımcılarına rehberlik etmek amaçlanmıştır. Dört sürdürülebilir ve yenilenebilir enerji santral çeşidi değerlendirilmiştir; bunlar güneş, rüzgar, hidrolik ve LFG (çöp gazı) santralleridir. Alternatifleri değerlendirirken göz önünde bulunduracağımız birçok önemli kriter vardır ve bu problem çeşidi için çok ölçütlü karar verme (ÇÖKV) sistemlerinin uygulanması yerinde bir yaklaşımdır. Bu bağlamda teknik, ekonomik ve çevresel açıdan 22 değerlendirme kriteri belirlenmiştir ve üç farklı açıdan kriterleri bir araya getirmek değerlendirme işlemini daha kapsamlı hale getirmiştir. Bu çalışmayı iki farklı teknik uygulayarak gerçekleştirdik ve sonuçları karşılaştırdık. Genel anlamda tipik bir MCDM yöntemi alternatifleri belirlenen kriterlere göre sıralamaya koyar. Bu durumdan farklı olarak TODIM yöntemi alternatifleri sıralarken aynı zamanda risk faktörünü de değerlendirme işlemine katar. Yöntemin bu özelliği beklenti teorisine dayanır. VIKOR uygulamanın sonunda uzlaşık bir çözüm sunan güçlü bir MCDM tekniğidir. Bunun yanısıra, değerlendirme sürecimize risk faktörünü de eklemek istedik ve TODIM metodunu da uyguladık. Buna ek olarak belirsiz, muğlak ve müphem durumlara çözüm için bulanık küme teorisi VIKOR ve TODIM’ e entegre edilmiştir. Sonuç olarak bulanık VIKOR yöntemine göre

en iyi alternatif LFG enerjisi olarak elde edilmiştir ve onu sırasıyle güneş, rüzgar ve hidrolik enerji takip eder. Bulanık TODIM sonuçlarında ise iki farklı sıralama oluşmuştur. Azalma faktörü θ 1 ve 2.5' e eşit olduğunda güneş enerjisi en iyi seçenek olarak bulunmuş ve ikinci sırada LFG enerji, üçüncü sırada rüzgar ve son olarak hidrolik enerji yer almıştır. Bu faktör 3 ve 4'e eşit olduğunda sırala değişmiş, birinci sıraya LFG, ikinci sıraya güneş enerjisi geçmiştir; üçüncü ve dördüncü sıradaki alternatifler aynı kalmıştır.

1. INTRODUCTION

The current energy use and dependence of human beings are increasing inevitably. The majority of energy need (81%) is met from fossil resources all over the world (Tasri and Susiwalati, 2014). This high-level consumption rate has caused a rapid reduction of reserves and has been creating serious environmental problems. Fossil fuel utilization is a primary source of CO_2 emissions and only coal-fired plants, which are 40% of world energy production, are responsible more than 70% of total energy sector emissions (Foster and Bedrosyan, 2014). Additionally, fossil fuel reduction causes energy shortage in the next decades and therefore in both energy supply and environmental pollution side, unconscious consumption of fossil fuels should be lowered to an acceptable level. Consequently, in 1997 Kyoto Protocol has emerged as a concrete step for taking precaution and mainly the protocol necessitates the reduction of harmful emissions to 1990 levels. If we continue to emit greenhouse gas (GHG) emissions at the same level, most probably the global warming temperature threshold which is a limit temperature resulted in dangerous climate change will be exceeded in the next decades (Lowe et al., 2009). Under these circumstances, an urgent 50-70% emission reduction policy should be applied to stabilize global CO_2 concentrations at the 1990 level by 2100 (EEA). In order to draw attention of the world to this issue one more time, Paris Agreement has been declared in 2015. It is a long-term action plan to avoid climate change impacts and keep the warming temperature below the critique level of 2°C.

These scenarios show that if we don't take due precautions, we will be faced with serious dangers resulted from global warming in a short span of time. In relation to that, authorities have been seeking for a solution to overcome these problems. As a result of this, an orientation has been occurred towards renewable energy resources since it is one solution to both supplying energy need and reducing carbon emissions. Therefore, it becomes a trend followed by governments, companies, and researchers to utilize clean energy sources against increasing in energy demand and environmental problems.

Turkey is one of the signatory countries of Kyoto Protocol and its contribution to global warming in the last 150 years is at a rate of 0.04%. While greenhouse gas emission of Turkey was 187 million ton in 1990, it reached a level of 370 million ton in 2009 (DSİ, 2015). Doubling GHG emissions in 20 years stems from growing industrialization activities of Turkey in recent decades. Progress in the industry has led to increase in energy requirement of Turkey. As energy need of Turkey grows, it is still a foreign dependent country in terms of supplying energy requirement and only 28,5% of energy supply is from domestic production (Türkyılmaz, 2015). However it has rich renewable energy (RE) potentials and there are policies encouraging investors, companies, and universities to use RE systems for energy supply. 26.4% of Turkey's electricity generation is from RE resources and the biggest contributor with 24.5% is hydroelectric power plants (Atılgan and Azapagic, 2015). Our country aims to obtain 30% of energy production from RE sources by 2023 (EUAS, 2011). In order to reach this target, the government economically encourages investors to invest in sustainable and renewable energy sector. It provides purchase guarantee per kilowatt-hour generated electricity during specified years. After the government support policy, there has been an increase in energy investments. These are our main motivations to choose and study on the green energy systems.

It is important to choose the type of energy power plant, which the investors want to build. To this respect, one of the purposes of this study is to lead energy investors for this issue. We need to make a comprehensive evaluation of the alternatives to decide the best option. When we analyze sustainable and renewable energy operation systems, we should take into account many factors in technical, economical, environmental and social perspective. Therefore applying MultiCriteria Decision Making (MCDM) methods is an appropriate approach for this matter. By MCDM methods we are able to solve decision-making problems that may contain conflicting criteria within it and MCDM techniques increase the quality of decisions.

We determined to apply VIKOR technique among the plenty of MCDM methods because it has additional benefits, which enable maximum group utility of the majority with minimum individual regret of the opponent (Opricovic and Tzeng, 2004). Many researchers apply MCDM method by combining its techniques to reach better results. VIKOR studies follow this pattern and besides single applications of VIKOR, there are sheer number of studies combined with different approaches and technics. The most preferred combination with VIKOR is the fuzzy approach (Yazdani and Graeml, 2014) (Mardani et al., 2016). It is developed by Lotfi Zadeh in 1965 to cope with vagueness and uncertainty of the problems. When we analyze the energy power plants, we face fuzziness in data and it becomes difficult to define exact values. For example annual electricity production of solar, wind and hydropower heavily depend on seasonal conditions. The production amount may not be regular in every year. By fuzzy set theory, we are able to define an accurate interval rather than assigning an exact value. Therefore we integrated fuzzy approach into VIKOR and it will improve the quality of results in our study.

In the second part of the study, in order to test the consistency of the results obtained by VIKOR technique we wanted to apply a different method and solve the problem. We will compare the results and see how the ranked lists of alternatives are changed in the application part.

In real life problems, risk always exists and it is an important factor in decision- making process. However, most of the MCDM techniques are not able to cope with risk or do not consider risk factor in their methodologies. As second MCDM technique to solve our problem we chose TODIM (an acronym in Portuguese of Interactive and Multicriteria Decision Making) method so that we can add risk factor on our decision-making problem. Renewable energy power plants include a lot of risk from many different aspects. Especially solar, wind and hydraulic power plants are dependent on season conditions. For example, rain level is a risk factor for hydraulic energy power plants. If areas of the hydraulic power plants have low rain rate in the current year, it affects the energy production amount negatively. Therefore adding risk factor to energy power plants evaluation problems is a necessary approach to receive consistent and reliable results.

TODIM is a discrete MCDM technique based on prospect theory and deals with risk in decision-making process. Prospect theory is developed by Kahneman and Tversky (1979) and it is proposed to be a descriptive model, alternative to utility theory for decision making under the condition of risk. The theory reveals that people rely on the potential value of gains and losses rather than the final outcome when they make a decision. This feature of the theory contradicts with utility theory because utility theory assumes that people make rational decisions based on final outcome. The prospect theory has a value function and it is defined on deviations from a reference point (Kahnemann and Tversky, 1979). The value function is an S-shaped and shows gains and losses. The function generally shows a concave characteristic above the reference point, meaning risk aversion in case of gains; and commonly convex characteristic below the reference point, which represents propensity to risk in case of losses (Rangel et al., 2010). Risk aversion in the case of gain refers that people prefer certain or high probable gains even they have a chance to earn much more than that gain if they take a risk. Risk propensity in the case of losses refers that when people are faced with loss, they are willing to take a risk if there is a chance to earn. After that, it is understood that equal amount of gain and loss don't have equal importance for people, fear of loss outweighs gain. This finding of Kahneman brings him Nobel economy prize in 2002.

In TODIM method gains and losses of each alternative over another are calculated for each criterion. Pairwise comparison of alternatives leads us to find the best option among the alternatives. As it is in the prospect theory, TODIM has a value function as well and shape of the function of TODIM is the same as the value function of prospect theory. TODIM is a discrete method and is not able to cope with uncertain conditions. Therefore one more time we need to integrate fuzzy approach into TODIM methodology to increase the quality of results as we did for VIKOR. Integrated fuzzy TODIM method is not one of the widespread studies in literature and early studies can be found at the beginning of the 2000s (Nobre et al., 1999). In the last decade, there have been limited numbers of fuzzy TODIM applications such as studies of Tosun and

Akyüz (2015), Krohling and Souza (2012), Hanine et al. (2016). Besides Gomes and Rangel conducted the early studies of discrete TODIM method in 1992.

We performed a comprehensive real life study in energy field through this thesis. The evaluation criteria contain the most significant aspects of a power plant. Therefore it can be taken as a basis for another energy source selection studies and searches. Additionally we expect that this study will contribute to energy studies of Turkey and enrich the fuzzy VIKOR and fuzzy TODIM literature in renewable energy field.

To sum up in this study fuzzy VIKOR and fuzzy TODIM methods have been used to find best sustainable and renewable energy power plant option among the alternatives. This thesis study was formatted in the following way: After this introduction section, there will be an explanation of energy alternatives of the study, which is solar, wind, hydraulic and landfill gas. In the next part, fuzzy set theory and fuzzy MCDM models will be analyzed. After that section, application of VIKOR and TODIM methods will be conducted and finally ended up with sensitivity analysis and conclusion part.

2. LITERATURE REVIEW

Since the global warming and its inevitable impacts on all living creatures become a current issue of the world, there has been an increase in energy studies. The literature is very rich in clean energy studies with MCDM methods. Sustainable energy includes renewable energy sources, thereby the studies center on selecting best renewable energy alternatives/technologies offered by authorities. Renewable energy power plants emerged as a reliable solution that saves the environment while producing energy. Moreover, limitation on the reserve of fossil fuels increases the popularity of renewable energy in recent years.

To analyze comprehensively sustainable energy alternatives, researchers have appealed to MCDM to find the best option according to problem conditions. There are several common criteria that are widely used in MCDM related to energy studies. These are energy and exergy efficiency; investment, operations and maintenance cost; CO_2, NO_X emissions, and land use; public opinion and employment in technical, economical, environmental and social categories respectively (Kaya and Kahraman, 2010). Determination of the criteria heavily depend on the nature of the study for instance, it can vary from country to country or relates whether the study is performed from government side or private sector.

If we analyze the RE energy studies over the past two decades, in 1997 Mirasgedis and Diakoulaki performed a cost analysis of electricity production systems including RE sources. They used MCDM method for identifying their environmental impacts. Iniyan and Sumathy (1998) presented a study to find an optimal RE model reducing cost-efficiency ratio and they also presented best utilization fields of RE sources. Beccali et al. prepared an action plan to spread RE technologies and used ELECTRE method to find the best technology in 2003. Afgan and Carvalho made an assessment study to specify RE power plant evaluation criteria in sustainability frame. They created sustainability index of the alternatives and accordingly made comparison in their study in 2001.

Kaya and Kahraman (2010) applied AHP and VIKOR techniques to obtain the best renewable energy option for Istanbul and the plant side of the best option under fuzzy environment. They used AHP method to reach criteria weights and utilized VIKOR for the remaining part. As a result, they found out wind energy and Çatalca district in terms of the best renewable energy type and its place. Same topic with different techniques and criteria was investigated to reach best energy policy and technology. In this regard, İ.Kaya and Kahraman (2010) preferred fuzzy AHP technique; Kahraman and Kaya (2011) applied modified fuzzy TOPSIS.

Zerpa and Yusta (2015) applied integrated AHP-VIKOR method in their study as Kaya and Kahraman (2010) conducted similar energy planning study for Istanbul. In order to be more realistic, they asked for four groups of expert's opinion in different sectors such as academia, private companies and determined the criteria weights. The authors highlighted that for the remote-rural area electricity production projects, there is a conflict between technical, economical criteria and social, environmental criteria. Finally, hybrid renewable technology systems were found as the best solution for their problem.

Şengül et al. (2015) analyzed RE resources in Turkey frame with fuzzy TOPSIS and applied Shannon's entropy methodology to find criteria weighted values. According to their criteria, the best option was hydropower for Turkey.

Tasri and Susilawati (2014) conducted a study for Indonesia and aimed to find the best RE alternative in terms of generating electricity. They evaluated RE resources with fuzzy AHP technique and found that hydropower is the most appropriate alternative for Indonesia. Streimikiene et al. (2012) had same research with different techniques MULTIMOORA and TOPSIS to find best sustainable electricity generation technologies. The authors suggest water and solar thermal resources in this regard.

Zhang et al. (2015) emphasized the conflicting criteria when an RE alternatives are evaluated and state that traditional MCDM methods are inadequate to overcome this matter. They proposed an improved model that is integrated with Choquet Integral and fuzzy approach.

Qin et al. (2017) extended classical TODIM method in their studies and proposed a fuzzy TODIM technique to solve multicriteria group decision-making (MCGDM) problems under the fuzzy environment where unknown situations exist. At the end, they presented an illustrative example selecting a renewable energy sources. They tried different values of attenuation factor, however the best alternative stayed the same as hydropower.

Almost every country goes through choosing an appropriate electricity production system. All over the world, there are many researchers who perform MCDM selection process for their countries. For example, San Cristobal worked on renewable energy project alternatives provided by Spanish Government within its energy policy. He performed VIKOR method and utilized AHP method for weighting process (2011). A similar study was done for Malaysia with different technique. In order to cope with uncertainty, the researchers applied intuitionistic fuzzy analytic hierarchy process (IF-AHP). It is a different scale to convert linguistic variable to numbers and obtained from initial AHP scale (Abdullah and Najib, 2014). Turskis et al. (2016) carry out a study for Lithonia to choose best electricity production system. They applied AHP methodology and obtained biomass energy as the best option. Also, a sensitivity analysis was done with ARAS (Additive Ratio Assessment method) but the result stayed the same. Zhao and Guo (2015) performed a study on the purpose of being a reference to Chinese government to make right energy policies. They implemented a hybrid MCDM method witch is divided in two parts; the superiority linguistic ratings and entropy weighting method for index weight determination and the fuzzy grey relation analysis for ranking alternatives. Their results showed that solar energy type is the best option with the biggest benefit followed by wind and biomass power. Al Garni et al. (2016) conducted a study using AHP method for Saudi Arabia to evaluate renewable power generation sources and obtained solar photovoltaic as the most favorable technology. Greece and Iran have more specific studies of wind energy in renewable energy alternatives. Shirgholami et al. (2016) applied selection process for wind turbine technologies by AHP method in Iran and Vagiona and Karanikolas (2012) used same method AHP to find out the most efficient area in electricity production to construct offshore wind farms in Greece.

As seen in the given studies above, variety of MCDM techniques are preferred for the selection of the best energy source. Naturally each one of them has strengths and weaknesses. They have been using appropriately according to problem conditions by researches. In the following, we will briefly explain frequently used and well-known MCDM techniques in the literature.

Saaty (1980) developed AHP (Analytical Hierarchy Process) and over the three decades it is one of the most used MCDM method. Saaty defines a scale from 1 to 9 to convert linguistic terms into numbers. For example 3 indicates moderately dominance and 9 extremely dominance. With the help of this scale, criteria weights are determined and priority of the alternatives is obtained based on the decision makers' pairwise evaluations. In 2006 Saaty defined a new method ANP (Analytical Network Process) which is a form of AHP. It works well in clustering, ranking groups and there can be dependent and indepented features in the problem (Velasquez and Hester, 2013). AHP and ANP are applied very frequently to be combined with other methods for decision-making problems.

Hwang and Yoon (1981) developed TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and in the model, best alternative is the alternative that is closest to the ideal solution and farthest from the negative ideal solution. There are many applications of TOPSIS in different fields. Advantage of the model is it has a simple process to implement and problem size doesn't effect on steps of the algorithm. As disadvantage, weighting criteria is a difficult phase and it doesn't consider relative importance of attributes (Velasquez and Hester, 2013) (Opricovic and Tzeng, 2004).

DEMATEL (Decision Making Trial and Evaluation Laboratory) method was developed by Battelle Memorial Institute of Geneva. It is well known with its strength to deal with cause and effect relationships in problems. Accordingly this property of the model, it enable us finding the criterion that effects other criteria the most. It has an extensive of application area and mostly implemented with other methods as integrated MCDM model.

ELECTRE (Elimination and Choice Expressing the Reality) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) are the outranking methods. ELECTRE and PROMETHEE methods use pairwise comparison between the alternatives for each criterion to determine superiority relation of the alternatives. As a different aspect, ELECTRE does not consider the difference level between alternatives when determining the ranking order while PROMETHEE measures the difference level (Strantzali and Aravossis, 2016).

In this study we decided to apply VIKOR and TODIM techniques to evaluate the power plants. VIKOR method provides us a compromise ranking list and a solution set with the benefit of maximizing the group utility. Besides TODIM is a relatively new and is not a frequently used technique in the literature. It has a unique feature for adding risk factor in decision-making mechanism. We have conducted a real life case study and therefore it is a proper action to consider and add risk effect in the case because risk always exists in real life conditions.

3. ENERGY ALTERNATIVES

Renewable energy potential in a country mostly depends on geographical features of that country. In respect to this, Turkey has the capacity to utilize renewable energy through its natural sources. We analyzed four types of energy alternatives among the most common green energy types in Turkey. These are solar, wind, hydraulic and landfill gas, and explained respectively in the following.

3.1 Solar Energy

Solar energy is produced by fusion process that converts hydrogen to helium in the center of the Sun. For the solar energy utilization, the most used technique is photovoltaic cells; it converts sunlight into the electric current on solar panels. Solar energy is an inexhaustible source and contains a vast amount of energy. According to World Energy Assessment data, the annual potential of solar energy is 1575-49837 exajoules, which is enough to meet world energy need since the total world energy consumption is 559.8 exajoule in 2012. Global solar energy capacity is 178 GW and the current installed capacity is able to meet 1.2 % of energy demand of the world (GSR, 2016).

Due to the geographical position of Turkey, it has high solar energy potential and this potential rate is 380 billion kWh/year (Şengül et al., 2015). Regarding regional solar energy potential distribution of Turkey, Southeastern Anatolia is in the first place. It is followed by Mediterranean, East Anatolia, Central Anatolia and Black Sea region respectively (YEGM, 2017). All over the country, there are large and small 1078 solar power plants and their total installed power is 860.63 MW[1]. The biggest power plant is in Konya Karatay with 18 MW installed power. Turkey generates 568 billion kWh

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[1] http://www.enerjiatlasi.com/gunes/

electricity from existing solar plants and it corresponds to 0.22% of total electricity need of the country[2].

Turkey has prepared a comprehensive plan in every field for 2023, which is the year of its hundredth anniversary. Energy plan of the government in terms of the renewable energy is to increase the share of renewable energy in the electricity generation of the country above thirty percent. Ministry of Energy and Natural Sources has set a target for solar energy utilization as reaching at least 3000 MW installed capacity by the end of 2023. It means we need to have more than two times of current installed power to achieve the objective. As of now, Turkey has six years and the target moves away from being a realistic objective for the country. On the other hand, there are under construction projects permitted by the government to be installed. After they enter into service, the installed solar energy capacity of Turkey will rise in numbers.

Another solar energy development project in Turkey is to increase the domestic production rate of solar energy technologies. At the present time, this rate is 17% and solar panels generate 65% of total cost. With home production of photovoltaic cells, the domestic production rate will raise to the level of 70% (Dermencioğlu, 2017).

The strength of the solar energy apart from other renewable energy alternatives is flexibility and variety of its usage. By means of this, there are wide ranges of applications of solar energy; it can be easily integrated on surfaces. Agriculture and horticulture, transportation as solar-powered vehicles and designing on architectural structures are effective areas of solar energy utilization.

3.2 Wind Energy

Wind energy is an inexhaustible, clean energy source and resulted from the kinetic energy of air in motion. Electricity is generated from wind energy through wind turbines; firstly it converts the kinetic energy of air in motion (wind) to the mechanical

[2] http://www.enerjiatlasi.com/gunes/

energy, and then to the electric power. Wind farms consist of many turbines and there are two types of wind farm based on location, which are onshore and offshore. Onshore wind farms refer to turbines located on land, while offshore wind farms are constructed in a water area. Turkey does not have an offshore wind farm yet. However, there is a new project with the capacity of 800 MW planned to end in 2025 to construct offshore wind farms in the seaside of Turkey (Yıldırım, 2015).

Wind energy is the most developed and commercially convenient energy type among the renewable energy alternatives (Albostan et al., 2009). Its historical background is based on 1887. Today the world has 433 GW installed capacity and 3.7% of global electricity need is supplied by wind power (GWEC, 2017a).

Turkey has started wind energy operations in 1998 in İzmir. Installed capacity of the country is 5789 MW and electricity generated from the wind corresponds 6.3% of annual energy consumption of Turkey[3]. Besides Turkey has prepared an energy policy for 2023 and the target for wind energy is to reach 20000 MW installed capacity. Accordingly wind power continues to grow in Turkey and investments are made in a successful manner. As an indication of this, Turkey is in the seventh place in the world for installing new wind power capacity in 2016 (GWEC, 2017b). Therefore there are new wind power plant projects approved by Energy Market Regulatory Authority of Turkey and when these projects are completed Turkey will have 10839 MW wind power installed capacity. After these developments, 12% of total electricity consumption of the country will be met from wind power plants[4]. Turkey has been approaching its 2023 objective through these progress and steadily continuous to grow in wind energy.

Although the improvements in wind energy and the country has high wind energy potential due to geographical position, Turkey underutilizes its potential. The current energy consumption generated from wind power corresponds to 4% of total potential (Şimşek, 2017). According to REPA (abbreviation of Wind Energy Potential Map), Ege

[3] http://www.enerjiatlasi.com/ruzgar/
[4] http://www.enerjiatlasi.com/ruzgar/

and Marmara seaside have the best wind energy potential in Turkey. Additionally, east part of the central Anatolia Region, in the middle of Toros Mountains and East Mediterranean have effective wind speed values to produce energy.

As well as developments in electricity production from wind energy, Turkey has been making progress also technologically in wind power. Turkey has created its own national wind turbine brand Milres additionally, there are private companies making domestic wind turbine production and design. Therefore wind energy generation systems do not cause total dependency on foreign sources, create employment and support the national economy.

3.3 Hydraulic Energy

Hydraulic energy results from the kinetic energy of fast flowing water. Flowing water from top to bottom rotates turbines and the kinetic energy is converted to electricity, which is called hydroelectricity, by hydroelectric power plants. Hydraulic energy is defined as renewable and inexhaustible energy source. However, it is important to note that it depends on the water cycle of the world and hydropower production is affected by fluctuations in rainfall. Waterpower has been used since ancient times and electricity production has begun in the late 1800s. Up until today it has been growing and reaching approximately 1064 GW total global capacity. Total renewable energy share of global electricity production is 23.7%, with 16.6% contribution of hydroelectricity (GSR, 2016).

Hydraulic energy is one of the most established electricity production systems of Turkey. Its historical background depends on 1902 and in the early republican period, advanced hydroelectric power plant projects had been conducted; Seyhan, Hirfanlı, Kesikköprü, Demirköprü and Kemer power plants are important projects, which belong to that period of time (Gökdemir et al., 2012). Afterward, Turkey has started the most comprehensive project in the history of the republic, which is GAP (abbreviation of Southeastern Anatolia Project), a regional development plan. Its preparation began in the 1970s and was implemented as a master plan in 1989. GAP involves 9 cities in the region and mostly focuses on agricultural irrigation and producing hydroelectricity. GAP area has 22 dams, 19 hydroelectric power plants and total Turkey hydroelectric production share of GAP is significant with its 44,4% contribution (GAP).

Streams in rough regions of the country have high hydroelectricity potential. In Turkey, gross hydroelectricity potential is 433 billion kWh/year, technical potential is 216 million kWh/year and economical potential is 164 billion kWh/year. In terms of gross potential, Turkey has 1.07 % of the world and 13.7 % of Europe's hydraulic energy potential (DSİ, 2013). Hydraulic energy is the most utilized renewable energy type in Turkey. It is able to meet 25% of total electricity consumption per year. Total installed capacity of hydroelectric power plants is 26681 MW and it refers to 56% economic potential usage (Yılmaz, 2012). Turkey has ranked the tenth country in the world for net installed power capacity (IEA, 2016). Installation capacity has been gradually increasing because there are new power plant investments which are in foundation or preparation phase. Besides the government plans to achieve 36 GW hydropower capacity by 2023. In the case of reaching 36 GW installation power, Turkey will be utilizing its whole hydroelectric energy potential (YEGM). In parallel with these developments, Turkey appears very close to achieving its 2023 hydropower target.

Apart from other renewable energy types, hydroelectric power plants are the least accepted electricity generation system by public among renewable energy sources. It has been criticized on the grounds that hydroelectricity power plants cause ecocide. Various opinions and discussions have been continuing on this issue.

3.4 Landfill Gas Energy

Landfill gas (LFG) is a complex mixture of gasses generated through anaerobic decomposition of waste by microorganisms in a landfill. LFG consists of approximately 50% methane, 50% carbon dioxide and other volatile organic compounds less than 1%. Methane is a more dangerous greenhouse gas 28 to 36 times than carbon dioxide (EPA, 2017). As long as LFG is not controlled; it causes pollution, security issues because of gas explosion risk, health problems and global warming in the long term. On the other hand, LFG can be utilized in various ways. The gas can be flared to generate electricity and also used directly for the following processes: as boiler, dryer, heater and for leachate evaporation (Shrestha et al., 2008). Additionally, it can be converted to a different type of gas high/medium-Btu fuel and used in natural gas pipelines. LFG is also used to produce compressed natural gas or liquefied natural gas to use in vehicles or sold commercially (EPA, 2017). By the help of LFG utilization methods, harmful methane emissions can be prevented from migrating into the atmosphere.

Among these utilization alternatives, energy production from LFG is an effective and smart way to construct sustainable cities. Turkey has launched landfill gas to energy projects under the municipal solid waste management programs. Municipalities are granted to built power plants for recycling and disposing of wastes. Among these power plants Odayeri solid waste disposal site is the most important LFG project. It is the biggest LFG power plant in Europe with 34 MW installed capacity (Şimşek, 2014). It produces 211 billion kWh electricity on the average per year and can power 66 thousand houses in İstanbul[5]. There are 28 active power plants in the country; electric energy is produced in 24 of 83 sanitary landfills and in 4 dump sites. Annually 1.38 billion MWh electric energy is produced from these power plants and this amount of energy is able to meet the electric requirement of 400 thousand houses (AA, 2017).

LFG energy is not a renewable and inexhaustible source as solar, wind and hydropower; it is a sustainable and clean power generation source. However, in many resources in the literature, it is counted as a type of biomass energy that is a renewable source. Biomass includes herbal biomass, forest and forestry product biomass, animal biomass and organic waste biomass resources. In the same manner, Ministry of Energy Resources of Turkey has listed LFG energy under the category of biomass energy source.

The government has set 2023 target of biomass energy to reach 1000 MW installed capacity. At the present time, Turkey has 467 MW biomass energy installed capacity[6].

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[5] http://www.enerjiatlasi.com/biyogaz/odayeri-cop-gazi-santrali.html
[6] http://www.enerjiatlasi.com/biyogaz

As the biomass energy projects increase in order to achieve the target, LFG energy installed capacity of Turkey will increase as well.

4. FUZZY SET THEORY

Fuzzy sets were proposed by Lotfi Zadeh as an extension of classical set in 1965. The word "fuzzy" is a statement used to express situations having no well-defined boundaries. In reality, people can experience fuzziness almost in every phase of daily life. For example, there is no determined temperature interval for hot coffee; it varies by people's perspective. Besides, human reasoning is not compatible with binary logic most of the time. It means that the answer of a question is not either yes or no/true or false every time; people add vague words like some, less, high, large etc. to their expressions. In order to deal with fuzziness in real life problems, we need a method taking into account human subjectivity and fuzziness of the situations. Regarding this matter, fuzzy set theory is able to overcome ambiguity, uncertainty, and vagueness in the problems.

4.1 Definition of A Fuzzy Set

Zadeh (1965) has specified a fuzzy set such that it is a class of objects with a continuum of grades of membership and this set allows its members to have different grade of membership from 0 to 1. In other words, an element either belongs or does not belong to a set in classical sets, which compatible with binary logic 0 or 1. Whereas in fuzzy sets, an element can partially belong to that set. The definition of a fuzzy set is as follows (Zimmermann, 2010):

If X is a collection of objects denoted generically by x, then a fuzzy set $\tilde{A}$ in X is a set of ordered pairs:

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)|x \in X)\} \qquad (4.1)$$

$\mu_{\tilde{A}}(x)$ is called the membership function (generalized characteristic function) which maps X to the membership space M. Its range is the subset of nonnegative real numbers whose supremum is finite.

Example (Dubois and Prade, 1980): Let U = {positive real numbers}, which is an infinite set. Then, the fuzzy set A = "real numbers close to 10" may be defined as $A = \{(x, \mu_{\tilde{A}}(x) | x \in U)\}$ with the function $\mu_A(x) = 1/\{1 + [(x-10)^2/5\}$,

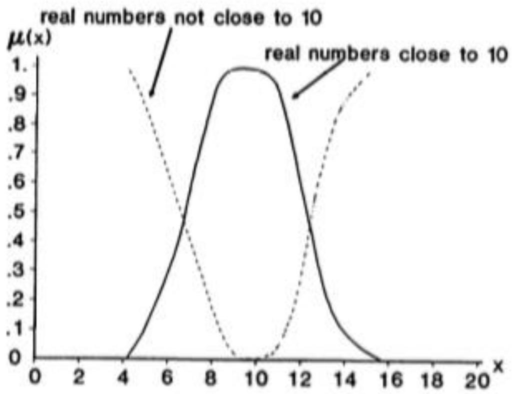

Fig. 4.1 The fuzzy set “real numbers close to 10”

Thus we can construct the fuzzy set as: $A =$
$\{\ldots(6, 0.24), ..(9, 0.83), (10, 1) \ldots., (14, 0.24) \ldots\}$

4.2 Fuzzy Numbers

If a fuzzy set is convex and normalized, and its membership function is defined in ℝ and piecewise continuous, it is called as fuzzy number. Normalization of a fuzzy set means that maximum degree of membership function is 1 (Gao et al., 2009).

There are different types of fuzzy numbers defined such as triangular, bell shaped, trapezoidal and we have preferred triangular fuzzy numbers (TFN) to implement in this study. TFN has more accuracy in results and provides the ease of computation (Tsai and Chou, 2011). TFN is defined as follows (Chen et al., 1992):

Let $x, l, m, u \in \mathbb{R}$ and $\mu_{\tilde{A}}(x)$ is a membership function of x in $\tilde{A}$. A triangular fuzzy number $\tilde{A} = (l, m, u)$ is defined such that:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x \leq l, \\ \frac{(x-l)}{(m-l)}, & l < x \leq m, \\ \frac{(u-x)}{(u-m)}, & m < x \leq u, \\ 0, & x > u. \end{cases} \tag{4.2}$$

where l is the lower bound and u is the upper bound and m is the most probable value of fuzzy number $\tilde{A}$. Fig. 4.2 illustrates TFNs graphically.

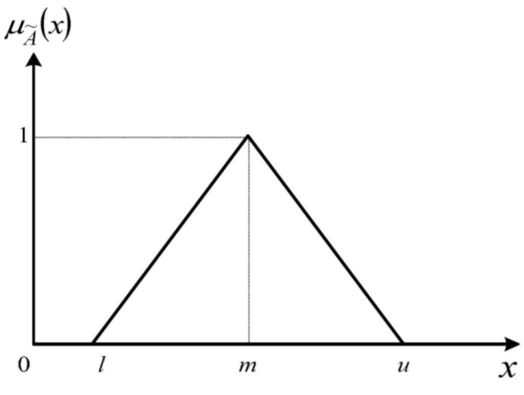

Fig. 4.2 Membership Function of a TFN

4.3 Linguistic Variables

Zadeh (1975) defined linguistic variable as a variable whose values are words or sentences in a natural or artificial language. For example, age is a linguistic variable if its values are linguistic rather than numerical. These values should be young, very young, old, not old etc. instead of 25, 18, 70, 45. In this regard, there are no certainly specified numerical age values for “young”. Fuzzy sets turn natural language into mathematics. The word young can be represented mathematically in the interval [0,1] that indicates the degree of being young (Zadeh, 1975).

We utilized linguistic variables in this study to estimate importance weight of the evaluation criteria and to assess performance of the alternatives according to qualitative criteria. Here linguistic variables were expressed by triangular fuzzy numbers. Table 4.1 and 4.2 show the corresponding fuzzy numbers of the variables (Chang, 2014).

Table 4.1: TFN values for the determination of the criteria weight

Linguistic Variables	Corresponding TFNs
Very Low (VL)	(0.0, 0.1, 0.2)
Low (L)	(0.1, 0.2, 0.3)
Medium Low (ML)	(0.2, 0.35, 0.5)
Medium (M)	(0.4, 0.5, 0.6)
Medium High (MH)	(0.5, 0.65, 0.8)
High (H)	(0.7, 0.8, 0.9)
Very High (VH)	(0.8, 0.9, 1.0)

Table 4.2: TFN values for the performance evaluation

Linguistic Variables	Corresponding TFNs
Very Poor (VP)	(0, 1, 2)
Poor (P)	(1, 2, 3)
Medium Poor (MP)	(2, 3.5, 5)
Fair (F)	(4, 5, 6)
Medium Good (MG)	(5, 6.5, 8)
Good (G)	(7, 8, 9)
Very Good (VG)	(8, 9, 10)

4.4 Fuzzy Number Operations

TFN has mathematical operations and some of them, which we applied in this study, are defined as follows (Opricovic, 2011):

Assuming $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$ are triangular fuzzy numbers.

i) Summation: $\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$

ii) Subtraction: $\tilde{A}_1 \ominus \tilde{A}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2)$

iii) Multiplication: $\tilde{A}_1 \otimes \tilde{A}_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2)\ for\ positive\ \tilde{A}_1$

iv) Scalar multiplication: $k \otimes \tilde{A} = (k \times l, k \times m, k \times u)\ for\ nonnegative\ k$

v) Scalar division: $\tilde{A} = (l/k, m/k, u/k)\ for\ positive\ k$

vi) MAX operator: $MAX_i \tilde{A}_i = (max_i l_i, max_i m_i, max_i u_i)$

vii) MIN operator: $MIN_i \tilde{A}_i = (min_i l_i, min_i m_i, min_i u_i)$

It is important to note some important properties of operations on triangular fuzzy numbers. They are (Gao et al., 2009):

1) The results from addition or subtraction between triangular fuzzy numbers result also triangular fuzzy numbers.

2) The results from multiplication or division are not triangular fuzzy numbers.

3) Max or min operation does not give triangular fuzzy number.

However it is often assumed that the operational results of multiplication or division are approximation of TFN.

5. FUZZY MULTI CRITERIA DECISION MAKING MODELS

Real life problems have a complex structure affected by many different factors. Therefore it should be considered from different angles to be solved successfully. Especially in decision-making problems, it is important to identify factors affecting the problem and accordingly deal with the problem from different aspects. For example, a machine has many features such as power, speed etc. and buying the machine among the plenty of brands and types necessitates both economic and technical analysis. Multi-Criteria Decision Making (MCDM) models are based on this approach and it is a tool that guides decision makers. International Society on MCDM defines it as “the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process”. It has a wide range of application field over the past three decades from health to energy industry.

Fuzzy Multi-Criteria Decision Making (FMCDM) models are decision-making methods integrated with fuzzy approach. Fuzzy technique is the most preferred combination with MCDM methods (Asemi et al., 2014). It copes with uncertain, vague and ambiguous situations of real life problems. There are several types of fuzzy sets used in studies i.e. type-2 fuzzy sets, intuitionistic fuzzy sets, and hesitant fuzzy sets. Applying FMCDM methods increases the quality of decision-making process. The most used application areas of fuzzy MCDM methods are computer science, engineering, mathematics, decision sciences, business and management, and environmental sciences (Kahraman et al., 2015).

In a typical MCDM problem, there are alternatives and one of them should be selected by decision makers as the best alternative to apply in their system. The basic principle of MCDM methods is to compute the score of each alternative with respect to criteria and rank the alternatives based on that score. For the quality of the selection process, it is significant to determine evaluation criteria in line with goals. MCDM methods may contain qualitative and quantitative criteria to analyze. Decision Makers specify the criteria weights in the evaluation process; they play an important role and consequently solution of the problems subject to their choice.

There are various MCDM models in the literature. ELECTRE, PROMETHEE, AHP, TOPSIS are examples for widely used MCDM methods. In this study, we implemented fuzzy VIKOR and fuzzy TODIM methods in our problem. VIKOR is a distance-based technique while TODIM achieves results through pairwise comparison. The details of the techniques were analyzed in the next part.

5.1 Fuzzy VIKOR

VIKOR method was developed by Opricovic in 1990 for multicriteria optimization of complex systems. It solves MCDM problems containing conflicting and noncommensurable (different unit) criteria (Opricovic, 2011). In case of having conflicting criteria in the problem, it is stated that VIKOR method focuses on ranking and selecting from alternatives. In this regard, the method provides a compromise ranking list and a solution set. The solution set includes the alternatives that a decision maker can choose as a solution for his/her problem. The compromise ranking is obtained by measuring distance of the alternatives to the ideal. In figure 2, it is illustrated that the compromise solution F^c is the closest point to the ideal F. The strength of the method is to provide a maximum ‘‘group utility’’ for the ‘‘majority’’ and a minimum of an individual regret for the ‘‘opponent’’ (Opricovic and Tzeng, 2004).

Development of the VIKOR technique is based on the following L_p metric form:

$$L_{pj} = \left\{\sum_{i=1}^{n}\left[w_i\,(f_i^* - f_{ij})/(f_i^* - f_i^-)\right]^p\right\}^{1/p}, \quad 1 \ll p \ll \infty; \quad j = 1,2,\ldots..J. \qquad (5.1)$$

L_{1j} produces S_j in equation 5.8 and $L_{\infty j}$ produces R_j in equation 5.9. The solution obtained by $\min_j S_j$ represents a maximum group utility and by $\min_j R_j$ represents minimum individual regret of the opponent (Opricovic and Tzeng, 2007).

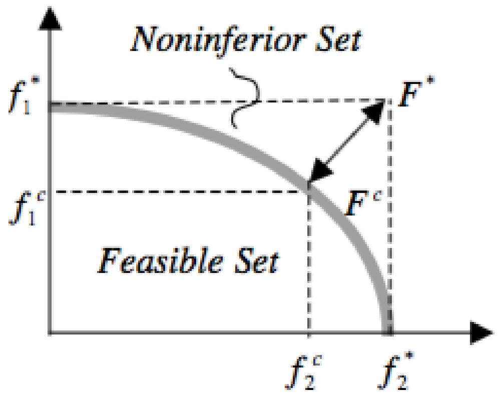

Fig. 5.1 Ideal and compromise solutions

In a similar manner, the fuzzy VIKOR method has been developed to achieve a compromise solution in a multicriteria decision making problem under fuzzy environment where both criteria and weights could be fuzzy sets. In this fuzzy MCDM problem, there are *m* number of alternatives *j=1, 2…m* and *n* number of criteria *i=1,2…n*. A_j indicates the *j*th alternative, C_i indicates the *i*th criterion. $\tilde{f}_{ij}$ is a triangular fuzzy number which is performance rating of *j*th alternative by ith criterion such that $\tilde{f}_{ij} = (l_{ij}, m_{ij}, r_{ij})$, l_{ij} and r_{ij} are the lower and upper bounds respectively, m_{ij} is most likely value of $\tilde{f}_{ij}$. I^b denotes the set of benefit criteria and I^c denotes cost criteria. To construct framework of the problem, we note that there are *m* alternatives, *n* evaluation criteria, and *k* decision makers. This system can be expressed in a matrix format such that:

$$\tilde{D} = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \cdots & A_m \end{array} \\ \begin{bmatrix} \tilde{f}_{11} & \tilde{f}_{21} & \cdots & \tilde{f}_{1m} \\ \tilde{f}_{21} & \tilde{f}_{22} & \cdots & \tilde{f}_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{f}_{n1} & \tilde{f}_{n2} & \cdots & \tilde{f}_{nm} \end{bmatrix} \end{array} \quad j = 1,2, \ldots., m; \quad i = 1,2, \ldots., n \tag{5.2}$$

$\tilde{D}$ is a performance matrix with *nxm* size, where $\tilde{f}_{ij}$ is the performance rating of alternative A_j evaluated by criterion C_i. It is formed as:

$$\tilde{f}_{ij} = \frac{1}{k}\left[\tilde{f}_{ij}^{1} \oplus \tilde{f}_{ij}^{2} \oplus \ldots . \oplus \tilde{f}_{ij}^{k}\right] \tag{5.3}$$

where $\tilde{f}_{ij}^{k}$ is the performance rating determined by kth decision maker of alternative *j* evaluated by *i*th criterion.

The fuzzy VIKOR method is described in the following steps (Opricovic, 2011).

Step1: Determination of fuzzy best $\tilde{f}_i^* = (l_i^*, m_i^*, r_i^*)$and fuzzy worst $\tilde{f}_i^\circ = (l_i^\circ, m_i^\circ, r_i^\circ)$ values of all criteria

$$\tilde{f}_i^* = MAX_j\, \tilde{f}_{ij}\,, \qquad \tilde{f}_i^\circ = MIN_j\, \tilde{f}_{ij} \qquad \text{for} \quad i \in I^b; \tag{5.4}$$

$$\tilde{f}_i^* = MIN_j\, \tilde{f}_{ij}\,, \qquad \tilde{f}_i^\circ = MAX_j\, \tilde{f}_{ij} \qquad \text{for} \quad i \in I^c. \tag{5.5}$$

Step2: Computation of normalized fuzzy difference $\tilde{d}_{ij}$

$$\tilde{d}_{ij} = (\tilde{f}_i^* \ominus \tilde{f}_{ij})/(r_i^* - l_i^\circ) \qquad \text{for} \quad i \in I^b; \tag{5.6}$$

$$\tilde{d}_{ij} = (\tilde{f}_{ij} \ominus \tilde{f}_i^*)/(r_i^\circ - l_i^*) \qquad \text{for} \quad i \in I^c. \tag{5.7}$$

Step3: Computation of $\tilde{S}_j = \left(S_j^l, S_j^m, S_j^r\right)$ and $\tilde{R}_j = \left(R_j^l, R_j^m, R_j^r\right)$. $\tilde{S}_j$ refers to distance of alternative *j* from the fuzzy best value, similarly $\tilde{R}_j$ is the distance from the fuzzy worst value.

$$\tilde{S}_j = \sum_{i=1}^{n} \oplus \; (\widetilde{w}_i \otimes \tilde{d}_{ij}) \tag{5.8}$$

$$\tilde{R}_j = MAX_i(\widetilde{w}_i \otimes \tilde{d}_{ij}) \tag{5.9}$$

$$\widetilde{w}_i = \frac{1}{k}\left[\widetilde{w}_i^1 \oplus \widetilde{w}_i^2 \oplus \ldots . \oplus \widetilde{w}_i^k\right] \tag{5.10}$$

where $\widetilde{w}_i$ is the fuzzy importance weight of ith criterion, which is determined by decision makers. $\widetilde{w}_i^k$ shows the fuzzy importance weight of ith criterion and determined by kth decision maker.

Step4: Computation of the values $\tilde{Q}_j = \left(Q_j^l, Q_j^m, Q_j^r\right)$ by the formula

$$\tilde{Q}_j = v(\tilde{S}_j \ominus \tilde{S}^*)/(S^{\circ r} - S^{*l}) \oplus (1-v)(\tilde{R}_j \ominus \tilde{R}^*)/(R^{\circ r} - R^{*l}) \tag{5.11}$$

where $\tilde{S}^* = MIN_j\ \tilde{S}_j$, $S^{\circ r} = MAX_j S_j^r$, $\tilde{R}^* = MIN_j\ \tilde{R}_j$, $R^{\circ r} = MAX_j R_j^r$ and while v is a weight to represent the maximum group utility, 1- v indicates the weight of the individual regret. v value can be estimated by $v = (n+1)/2n$ or could be 0.5 to compromise both side.

Step5: Defuzzification of $\tilde{S}_j, \tilde{R}_j\ and\ \tilde{Q}_j$. There are various ways of defuzzification operation applied in different studies. In this study, we prefer to use the equation that Opricovic (2011) used in his study to convert fuzzy numbers into crisp scores. It is as following:

$$Crisp\left(\widetilde{N}\right) = (2m + l + r)/4 \tag{5.12}$$

Step6: Ranking the alternatives by crisp value of S, R and Q in ascending order. There are three ranking lists $\{A\}_S, \{A\}_R, \{A\}_Q$.

Step7: Reaching the compromise solution

The alternative having the smallest Q value indicates the best option among the alternatives if the following conditions are satisfied.

C1. Acceptable Advantage

$$Q(A^{(2)}) - Q(A^{(1)}) \geq DQ \tag{5.13}$$

where $A^{(1)}$ and $A^{(2)}$ are first and second best alternative respectively in the Q ranking list. The threshold $DQ = 1/(J-1)$

C2. Acceptable stability in decision making

The best alternative $A^{(1)}$ must also be the best ranked by S or/and R. If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives $A^{(1)}$ and $A^{(2)}$ if only the condition C2 is not satisfied, or
- Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if the condition C1 is not satisfied; $A^{(M)}$is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M (the positions of these alternatives are ‘‘in closeness’’).

5.2 Fuzzy TODIM

Prospect theory creates the infrastructure of TODIM method. The theory and method presented individually in the following sections.

5.2.1 Preliminaries on Prospect Theory

TODIM method (an acronym in Portuguese for iterative multicriteria decision making) is an MCDM method based on prospect theory and it was proposed by Gomes and Lima (1992). Prospect theory was developed by Kahneman and Tversky (1979) and it is a proposed descriptive model for decision making under condition of risk. People's approach to taking risk changes by being in case of gain or lose. According to the theory, there is risk aversion attitude in the face of gain and propensity to risk in the face of lose. Prospect theory has a value function indicating risk aversion and risk propensity and it is described in the following expression:

$$v(x) = \begin{cases} x^{\propto} & if\ x \geq 0 \\ -\theta(-x)^{\beta} & if\ x < 0 \end{cases} \tag{5.14}$$

where $\propto$ and β are parameters related to gains and losses, respectively. θ parameter represents a characteristic of being steeper for losses than for gains. In case of risk aversion, $\theta > 1$. Kahneman and Tversky (1979) experimentally determined the values of $\propto = \beta = 0{,}88$, and $\theta = 2.25$. Further, they suggest that the value of θ is between 2.0 and 2.5 (Krohling and Souza, 2012). This function is S-shaped as shown in figure 5.2.

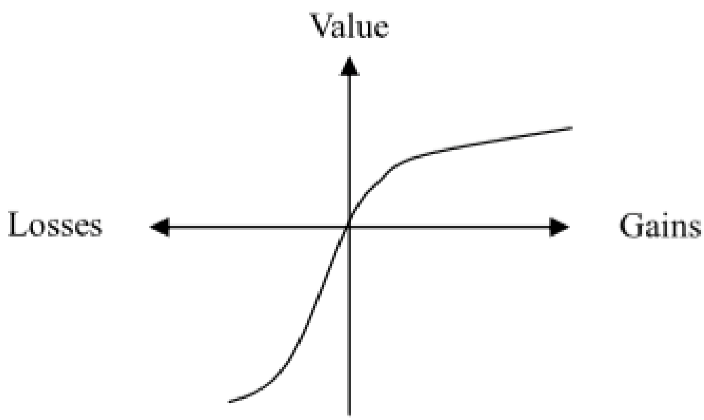

Fig. 5.2 The value function of prospect theory

Concave curve represents the gains and convex curve represents the losses. As it is in the prospect theory, TODIM has a value function as well and its shape is the same as the value function of prospect theory as shown in figure 5.2.

5.2.2 Fuzzy TODIM Method

Fuzzy TODIM is an integrated model of fuzzy sets with traditional TODIM. The method makes pairwise comparison between alternatives with regard to each criterion and gains and losses of each alternative over the others are obtained. The sum of gains and loses of each alternative gives dominance degree of that alternative. In the final step, alternatives are ranked by these dominance degrees.

Let there are m number of alternatives $i = 1,2 \ldots m$ and n number of evaluation criteria $j = 1,2 \ldots n$. A_i denotes the ith alternative, C_j denotes the jth criterion. Each criterion has different importance degree and $w = (w_1, w_2 \ldots w_n)^T$ is a weight vector, where w_j

denotes the importance weight of criterion C_j, such that $\sum_{j=1}^{n} w_j = 1$ and $0 \leq w_j \leq 1$. Alternatives have a performance value for each criterion. $\tilde{x}_{ij}$ is a performance value of *i*th alternative with respect to *j*th criterion. Note that w_j is a discrete number and $\tilde{x}_{ij}$ is a triangular fuzzy number.

The steps of the fuzzy TODIM method are organized by using studies of Tosun and Akyüz (2015), Xiao and Zhi-ping (2011), Sen et al. (2016).

Step 1: Determination of criteria weight and performance values of alternatives
For the performance evaluation of alternatives according to qualitative criteria and determination of criteria weights, triangular fuzzy numbers are used in this fuzzy TODIM method. Alternatives have numerical values for quantitative criteria. Performance evaluation and weight determination processes are conducted by decision makers. The equations are in the following:

$$\tilde{x}_{ij} = \frac{1}{k}\left[\sum_{e=1}^{k} \tilde{x}_{ij}{}^{e}\right] \qquad i = 1,2 \dots m \tag{5.15}$$

where $\tilde{x}_{ij}^{e}$ is the performance rating determined by eth decision maker of alternative *i* evaluated by *j*th criterion. *k* is the number of decision makers.

$$\widetilde{w}_j = \frac{1}{k}\left[\sum_{e=1}^{k} \widetilde{w}_j{}^{e}\right] \qquad j = 1,2 \dots n \tag{5.16}$$

where $\widetilde{w}_j^{e}$ is the weight of *j*th criterion, determined by eth decision maker. If performance values are in different units, normalization of the values is necessary. The fuzzy normalized value of $\tilde{x}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is $\tilde{r}_{ij}$ and calculated as:

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^*}, \frac{m_{ij}}{u_j^*}, \frac{u_{ij}}{u_j^*}\right), \qquad j \in B \tag{5.17}$$

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}}\right), \qquad j \in C \tag{5.18}$$

B and C are the set of benefit and cost criteria respectively. $u_j^* = max_i u_{ij}$ if $j \in B$, $l_j^- = min_i l_{ij}$ if $j \in C$. This normalization method standardizes the fuzzy performance values and makes the value range between 0 and 1, i.e. [0,1].

Step 2: Defuzzification of fuzzy criteria weights

Defuzzification method used in this study belongs to Abdel-Kader and Dugdale (2001). α is index of optimism. Bigger values of α represent an optimistic decision maker, whereas smaller values represent a pessimistic decision maker. α parameter reflects the decision maker's risk attitude. For example, a decision maker who avoids risk because of uncertain situations may prefer a low value of α. Different index of optimism values can be used in researches for sensitivity analysis. In this study index of optimism (α) is accepted as 0.5, which is a neutral point in order to balance between optimism and pessimism.

Let $\alpha \in [0,1]$ be index of optimism. For a triangular fuzzy number $\tilde{F}_j = (l_j, m_j, u_j)$ $j = 1,2 \ldots n$; let $V(\tilde{F}_j)$ be the value of $\tilde{F}_j$ and ordering can be calculated as;

$$V(\tilde{F}_j) = m_j \left\{ \alpha \left[\frac{u_j - x_{min}}{x_{max} - x_{min} + u_j - m_j} \right] + (1 - \alpha) \left[1 - \frac{x_{max} - l_j}{x_{max} - x_{min} + m_j - l_j} \right] \right\} \tag{5.19}$$

where $x_{min} = \inf S$, $x_{max} = \sup S$

$$S = \bigcup_{j=1}^{n} S_j \tag{5.20}$$

and $S_j = (l_1, m_1, u_1, \ldots \ldots \ldots, l_n, m_n, u_n)$ $\qquad j = 1,2 \ldots n$ (5.21)

Calculated weights with the ordering method are normalized by the following formula:

$$w_j = \frac{V(\tilde{F}_j)}{\sum_{j=1}^{n} V(\tilde{F}_j)} \tag{5.22}$$

Step 3: Calculation of Gains and Loses

Gains and losses of an alternative over the other alternatives are estimated by pairwise comparison. Let $\tilde{x}_{ij}$ and $\tilde{x}_{kj}$ are performance values of alternative A_i and A_k

respectively regarding to criterion C_j, $k = 1,2 \ldots m$. The performance values $\tilde{x}_{ij}$ and $\tilde{x}_{kj}$ are represented by TFNs. The Euclidian distance between them are calculated by the following equation:

$$d(\hat{x}_{ij}, \hat{x}_{kj}) = \sqrt{\frac{1}{3}\left[\left(x_{ij}^{l} - x_{kj}^{l}\right)^2 + \left(x_{ij}^{m} - x_{kj}^{m}\right)^2 + \left(x_{ij}^{u} - x_{kj}^{u}\right)^2\right]} \quad (5.23)$$

Gains (G_{ik}^{j}) and losses (L_{ik}^{j}) of A_i against A_k regarding to criterion C_j are given as:

For benefit criteria:

$$G_{ik}^{j} = \begin{cases} d(\hat{x}_{ij}, \hat{x}_{kj}), & \hat{x}_{ij} \geq \hat{x}_{kj} \\ 0, & \hat{x}_{ij} < \hat{x}_{kj} \end{cases} \quad (5.24)$$

$$L_{ik}^{j} = \begin{cases} 0, & \hat{x}_{ij} \geq \hat{x}_{kj} \\ -d(\hat{x}_{ij}, \hat{x}_{kj}), & \hat{x}_{ij} < \hat{x}_{kj} \end{cases} \quad (5.25)$$

For cost criteria:

$$G_{ik}^{j} = \begin{cases} 0, & \hat{x}_{ij} \geq \hat{x}_{kj} \\ d(\hat{x}_{ij}, \hat{x}_{kj}), & \hat{x}_{ij} < \hat{x}_{kj} \end{cases} \quad (5.26)$$

$$L_{ik}^{j} = \begin{cases} -d(\hat{x}_{ij}, \hat{x}_{kj}), & \hat{x}_{ij} \geq \hat{x}_{kj} \\ 0, & \hat{x}_{ij} < \hat{x}_{kj} \end{cases} \quad (5.27)$$

It is obvious that $G_{ik}^{j} + L_{ki}^{j} = 0$ and $G_{ii}^{j} = L_{ii}^{j}$=0. Using the equations, gain matrix $G_j = \left[G_{ik}^{j}\right]_{mxm}$ and loss matrix $L_j = \left[L_{ik}^{j}\right]_{mxm}$ are constructed for each criterion.

Step 4: Calculation of criteria's relative weights w_{jr}

Relative weights of criteria are estimated based on a reference criterion. It is the criterion with highest weight. Let C_r be the reference criterion, the relative weight w_{jr} of criterion C_j to the reference criterion C_r is found as follows:

$$w_{jr} = w_j / w_r \quad (5.28)$$

where w_j is the weight of criterion C_j and w_r is the weight of the reference criterion C_r.

Step 5: Construction of dominance degree matrix

$\phi_{ik}^{j(+)}$ denotes the dominance degree of gain and $\phi_{ik}^{j(-)}$ denotes dominance degree of loss. To construct the matrix, dominance degree of alternative A_i over A_k for criterion C_j is calculated with the following equations.

$$\phi_{ik}^{j(+)} = \sqrt{G_{ik}^{j}\, w_{jr} / \left(\sum_{j=1}^{n} w_{jr}\right)} \quad (5.29)$$

$$\phi_{ik}^{j(-)} = -\frac{1}{\theta}\sqrt{-L_{ik}^{j}\left(\sum_{j=1}^{n} w_{jr}\right) / \left(w_{jr}\right)} \quad (5.30)$$

where θ is attenuation factor of the loss. Overall dominance degree ϕ_{ik}^{j} is found as follows:

$$\phi_{ik}^{j} = \phi_{ik}^{j(+)} + \phi_{ik}^{j(-)} \quad (5.31)$$

after that dominance degree matrix $\phi_j = \left[\phi_{ik}^{j}\right]_{mxm}$ for criterion C_j can be constructed.

Step 6: Construction of overall dominance degree matrix

Overall dominance degree of alternative *i* on alternative *k* is calculated by:

$$\delta_{ik} = \sum_{j=1}^{n} \phi_{ik}^{j} \quad (5.32)$$

It creates an $m \times m$ size dominance degree matrix Δ and $\Delta = [\delta_{ik}]_{mxm}$.

Step 7: Calculation of overall value of each alternative and ranking the alternatives

Based on matrix Δ, the overall value of alternative A_i can be calculated as follows:

$$\xi(A_i) = \frac{\sum_{k=1}^{m} \delta_{ik} - min_{i\epsilon M}\{\sum_{k=1}^{m} \delta_{ik}\}}{max_{i\epsilon M}\{\sum_{k=1}^{m} \delta_{ik}\} - min_{i\epsilon M}\{\sum_{k=1}^{m} \delta_{ik}\}} \tag{5.32}$$

$0 \leq \xi(A_i) \leq 1$ and greater $\xi(A_i)$ indicates better alternative. Therefore the alternatives are ranked according to descending order of overall value $\xi(A_i)$.

6. AN APPLICATION: EVALUATION OF SUSTAINABLE AND RENEWABLE ENERGY POWER PLANTS

There has been a development in renewable energy investments over the last decade in Turkey, depending upon the developments all around the world. Turkish government supports the investments by providing purchase guarantee for electricity production. We aim to find out the best performing sustainable and renewable energy alternative and by means of this to lead the energy investors. We conducted this study based on four most common sustainable and renewable energy power plant types in Turkey, which are solar energy (SE), wind energy (WE), hydraulic energy (HE) and specifically land filled gas energy (LFG-E) consisting of solid waste under the category of biomass.

In this study, we worked with experts in their field and powerful companies in energy sector. An assistant professor from energy institute of İstanbul Technical University helped us for technical aspects of the power plants and made significant review for the criteria determination and performance evaluation. Besides we have received data of LFG, solar and wind power plants from a company working internationally and an important actor of energy sector of Turkey with 30 years of experience. We also received help from the manager of this company's energy trading investments department. Hence their knowledge and expertise in the energy field increases the quality and accuracy of our study. Additionally, hydraulic energy data was taken from another company developing and investing in power and water infrastructure and it is qualified by World Bank.

In total we have four decision makers, two of them are academicians whose area of expertise is renewable energy and the others are expert engineers in the field of energy trading and investment.

Assessment of the power plants will be done with two different techniques. These are fuzzy VIKOR and fuzzy TODIM methods. The results obtained from two techniques will be compared and we will try to find out a consistent solution in this problem.

6.1 Application of Fuzzy VIKOR Technique

6.1.1 Determination of Evaluation Criteria

One of the most important aspects of the multicriteria problem is to determine evaluation criteria properly. In this study, firstly we utilized the literature to choose energy evaluation criteria afterwards revised with the decision makers. As the most frequently adopted criteria in the energy evaluation studies are used, there are some rarely used criteria such as government support rate and cost increasing rate (Büyüközkan and Güleryüz, 2017). After the carefully investigation of the energy production subject, we determined the criteria list that needs to be considered to evaluate sustainable energy power plants. In the following table, this criteria list was presented and necessary information related to them was given (Şengül et al., 2015) (Cavallaro and Ciraolo, 2005).

Table 6.1: Evaluation criteria for power plants

Criterion	Description	Units
C_1: Technical efficiency	It is the amount of useful energy that we can gain from an energy source.	ratio
C_2: Technical risk	The probability of loss resulted from process of a power plant and effects of environmental conditions on the plants i.e rain, icing.	-
C_3: Maturity	It measures the availability of technology and its reliability.	-
C_4: Net annually electricity production	It refers to net amount of energy generated from an energy source at the end of the year.	MWh/year
C_5: Construction time	It is the length of construction period for the RE plants.	months
C_6: Land use	It represents annual net electricity per m^2.	kWh/m^2
C_7: Per unit installed power	It is the installed power of the plant per km^2.	MW/km^2

C_8: Plant lifetime	It is the service life of the plants.	year
C_9: Reserve potential	It states Turkey's RE energy potential	MW
C_{10}: Annual income	It is the annual income obtained from power plants' operations.	cent/kWh
C_{11}: Investment cost	It contains all type of costs related to equipment, installation, construction and engineering services.	cent/kWh
C_{12}: Total operating cost	It refers to costs due to energy plants' s operation, repair and maintenance activities including personal and service facility costs.	cent/kWh
C_{13}: Payback period	It is the time of repay period of investments.	year
C_{14}: Government support rate	It refers to rate of guarantee of electricity purchase by the government.	cent/ kWh
C_{15}: Operation and maintenance cost increasing rate	It refers to increasing cost rate over the years related to RE plant's operations and maintenance activities.	% (percentage)
C_{16}: Employment	It refers job creation in the RE plants.	number
C_{17}: Lifecycle GHG emissions	Generation of greenhouse gas emissions due to plant operations. These gasses are hazardous and cause global warming. CO_2, CH_4, N_2O etc.	ton/year
C_{18}: GHG emissions avoided	When we produce an amount of electricity from clean energy sources, conventional energy systems don't have to be used produce that amount of electricity. In this case the RE system prevents CO_2 emissions generating from conventional plants.	CO_2 –eq kg/kWh
C_{19}: Impact on ecosystem	It refers to potential risk to ecosystem that may be caused by RE plants, including liquid and solid disposals and costs caused by them, magnetic hazard, changing of microclimate and causing bad smell.	-
C_{20}: Social acceptability	It refers to public opinion about RE plants.	-
C_{21}: Noise	It measures the noise level caused by RE plants.	-
C_{22}: Visual impact	It evaluates visual pollution caused by RE plants.	-

Note: [-] denotes not having a unit because they are qualitative criteria.

We can categorize the criteria as technical from C_1 to C_9, economical from C_{10} to C_{16}, and economical from C_{17} to C_{22}.

To estimate importance weight, a questionnaire was prepared and sent to the decision makers. They evaluated all the criteria individually by referring the linguistic variables in table 4.1. Table 6.2 shows the decision makers' opinions on how important the mentioned criteria are. By using equation 5.10, we synthesized four different opinions on one criterion by averaging corresponding TFN values given by the decision makers. Calculation steps were explicitly provided in the following:
Fuzzy importance weight and crisp score of criterion C_1:

$$\tilde{w}_1 = \frac{1}{4}[(0.8, 0.9, 1.0) \oplus (0.7, 0.8, 0.9) \oplus (0.8, 0.9, 1.0) \oplus (0.8, 0.9, 1.0)]$$
$$= (0.775, 0.875, 0.975)$$

$$Crisp(\tilde{w}_1) = \frac{2(0.875) + 0.775 + 0.975}{4} = 0.875$$

The other criteria weights and crisp scores are calculated in the same way. Consequently, the criteria and their fuzzy weights are shown in table 6.3. The crisp score column of table 6.3 indicates the order of importance of each evaluation criterion. According to table 6.3 the first three important criteria are technical efficiency, government support rate, GHG emission avoided, impact on ecosystem and investment cost. It proves that technical, economical and environmental aspects should be analyzed together for a power plant evaluation.

6.1.2 Creating of the Performance Matrix

Before creating the decision matrix, we need to specify the criteria by their features. We have 5 qualitative criteria such as visual impact, maturity and 17 quantitative criteria such as electricity production amount, payback period. C_2, C_5, C_{11}, C_{12}, C_{13}, C_{15}, C_{17}, C_{19}, C_{22} are defined as cost criteria stating drawback and the rest are defined as benefit criteria stating advantage. For the qualitative criteria, the decision makers rated the alternatives by referring table 4.2. In order not to cause confusion for the decision makers, we wanted they to assume all qualitative criteria as benefit. For example; when solar energy is rated in terms of noise, if a decision maker evaluates it as very good (8,9,10), it does not mean that solar energy is very noisy it states solar energy is in a very good condition in terms of noise, doesn't cause high undesirable noise level. Table 6.4 shows the decision makers' evaluation rates with respect to the qualitative criteria.

Table 6.2: Decision makers' opinions on criteria importance

Criteria	D1	D2	D3	D4
C_1	VH	H	VH	VH
C_2	H	VH	MH	VH
C_3	H	H	VH	H
C_4	VH	M	VH	VH
C_5	MH	L	MH	MH
C_6	L	H	M	MH
C_7	L	H	M	MH
C_8	H	MH	VH	M
C_9	VH	H	H	H
C_{10}	VH	M	VH	VH
C_{11}	VH	MH	VH	VH
C_{12}	H	H	VH	H
C_{13}	H	MH	H	VH
C_{14}	VH	H	VH	H
C_{15}	MH	H	VH	H
C_{16}	MH	L	M	L
C_{17}	H	VH	MH	H
C_{18}	H	VH	VH	H
C_{19}	H	VH	VH	H
C_{20}	M	H	VH	H
C_{21}	L	H	MH	H
C_{22}	L	VH	MH	L

As in equation 5.3, we estimated the performance rating of the alternatives by averaging corresponding TFN values given by the decision makers. Performance value of alternative 1, which is solar energy for second criterion is presented as an example:

$$\tilde{f}_{21} = \frac{1}{4}\left[(4,5,6) \oplus (7,8,9) \oplus (7,8,9) \oplus (8,9,10)\right] = (6.5, 7.5, 8.5)$$

On the other hand for the quantitative criteria, we did not consult the judgments of the decision makers on the power plants because we have given numeric data for each alternative. Fuzzy performance values of the alternatives regarding to qualitative and quantitative criteria were gathered and table 6.5 shows the fuzzy performance ratings of all the alternatives.

Table 6.3: Fuzzy importance weights of the criteria

Criteria	Fuzzy importance weight	Crisp Score
C_1	(0.775, 0.875, 0.975)	0.875 [1]
C_2	(0.7, 0.813, 0.925)	0.813 [6]
C_3	(0.725, 0.825, 0.925)	0.825 [5]
C_4	(0.7, 0.8, 0.9)	0.8 [7]
C_5	(0.175, 0.313, 0.45)	0.313 [15]
C_6	(0.433, 0.55, 0.667)	0.55 [12]
C_7	(0.433, 0.55, 0.667)	0.55 [12]
C_8	(0.6, 0.713, 0.825)	0.713 [10]
C_9	(0.733, 0.833, 0.933)	0.833 [4]
C_{10}	(0.7, 0.8, 0.9)	0.8 [7]
C_{11}	(0.725, 0.838, 0.95)	0.838 [3]
C_{12}	(0.725, 0.825, 0.925)	0.825 [5]
C_{13}	(0.675, 0.788, 0.9)	0.788 [8]
C_{14}	(0.75, 0.85, 0.95)	0.85 [2]
C_{15}	(0.675, 0.788, 0.9)	0.788 [8]
C_{16}	(0.275, 0.388, 0.5)	0.389 [14]
C_{17}	(0.675, 0.788, 0.9)	0.788 [8]
C_{18}	(0.75, 0.85, 0.95)	0.85 [2]
C_{19}	(0.75, 0.85, 0.95)	0.85 [2]
C_{20}	(0.65, 0.75, 0.85)	0.75 [9]
C_{21}	(0.5, 0.613, 0.725)	0.613 [11]
C_{22}	(0.375, 0.488, 0.6)	0.488 [13]

Note: [ ] denotes importance order of the criteria.

Table 6.4: Decision makers' opinions on performance ratings of the alternatives

		C_2	C_3	C_{19}	C_{20}	C_{21}	C_{22}
D_1	SE	F	F	G	VG	G	G
	WE	F	G	G	VG	F	G
	HE	G	G	P	P	P	P
	LFG-E	P	G	VG	VG	F	F
D_2	SE	G	VG	VG	MG	VG	P
	WE	G	MG	VG	F	VP	P
	HE	G	MP	P	P	P	MP
	LFG-E	F	G	MP	VP	P	VP
D_3	SE	G	VG	G	VG	VG	G
	WE	G	VG	F	MG	F	MG
	HE	G	VG	MP	MG	F	F
	LFG-E	F	MG	VG	G	G	F
D_4	SE	VG	VG	VG	VG	VG	VG
	WE	VG	VG	VG	VG	F	G
	HE	VG	VG	G	VG	P	VG
	LFG-E	G	G	VP	MG	F	F

6.1.3 Calculation of Normalized Fuzzy Differences

After we obtained the performance matrix, equation 5.4 and 5.5 were used to specify fuzzy best and worst values (Table 6.6). Here it is important to note that we assumed all qualitative criteria as benefit to make evaluation process convenient for the decision makers. In this case, cost criteria are C_5, C_{11}, C_{12}, C_{13}, C_{15} and C_{17} in our problem. They are construction time, investment cost, total operating cost, payback period, operation and maintenance cost increasing rate, and lifecycle GHG emissions respectively.

Table 6.5: Performance matrix of the alternatives

	SE	WE	HE	LFG-E
C_1	(0.15,0.187,0.22)	(0.25,0.29,0.4)	(0.3,0.364,0.5)	(0.8,0.913,0.95)
C_2	(6.5,7.5,8.5)	(6.5,7.5,8.5)	(7.25,8.25,9.25)	(3.25,4.25,5.25)
C_3	(7,8,9)	(7,8.125,9.25)	(6.25,7.375,8.5)	(6.5,7.625,8.75)
C_4	(44580.375,44625,44669.625)	(79929.99,80010,80090.01)	(55069.875,55125,55180.125)	(293706,294000,294294)
C_5	(11.538,11.55,11.562)	(14.685,14.7,14.715)	(25.175,25.2,25.225)	(12.587,12.6,12.613)
C_6	(127.373,127.5,127.628)	(7.993,8.001,8.009)	(0.209,0.21,0.21)	(587.412,588,588.588)
C_7	(77.922,78,78.078)	(3.147,3.15,3.153)	(0.066,0.066,0.066)	(73.427,73.5,73.574)
C_8	(31.469,31.5,31.532)	(26.224,26.25,26.276)	(51.399,51.45,51.501)	(36.713,36.75,36.787)
C_9	(58741.2,58800,58858.8)	(50349.6,50400,50450.4)	(49821.978,49871.85,49921.722)	(3978.667,3982.65,3986.633)
C_{10}	(14.809,14.824,14.838)	(7.343,7.35,7.357)	(27.939,27.967,27.995)	(13.951,13.965,13.979)
C_{11}	(71.082,71.153,71.224)	(64.699,64.764,64.829)	(57.143,57.2,57.257)	(17.607,17.625,17.643)
C_{12}	(0.864,0.865,0.866)	(0.688,0.689,0.69)	(2.27,2.272,2.275)	(1.124,1.125,1.126)
C_{13}	(7.343,7.35,7.357)	(10.49,10.5,10.511)	(10.49,10.5,10.511)	(5.245,5.25,5.255)
C_{14}	(13.636,13.65,13.664)	(6.818,6.825,6.832)	(5.769,5.775,5.781)	(14.685,14.7,14.715)
C_{15}	(3.409,3.413,3.416)	(7.552,7.56,7.568)	(13.636,13.65,13.664)	(5.245,5.25,5.255)
C_{16}	(10.49,10.5,10.511)	(7.343,7.35,7.357)	(25.175,25.2,25.225)	(52.448,52.5,52.553)
C_{17}	(13,85,731)	(6,26,124)	(2,26,237)	(10,45,101)
C_{18}	(0.895,0.896,0.897)	(0.895,0.896,0.897)	(0.895,0.896,0.897)	(7.84,7.848,7.856)
C_{19}	(7.5,8.5,9.5)	(6.75,7.75,8.75)	(2.75,3.875,5)	(4.5,5.625,6.75)
C_{20}	(7.25,8.375,9.5)	(6.25,7.375,8.5)	(3.75,4.875,6)	(5,6.125,7.25)
C_{21}	(7.75,8.75,9.75)	(3,4,5)	(1.75,2.75,3.75)	(4,5,6)
C_{22}	(5.75,6.75,7.75)	(5,6.125,7.25)	(3.75,4.875,6)	(3,4,5)

In the next step, equation 5.6 and 5.7 were applied to calculate the normalized fuzzy difference. In the following, an example of normalization in terms of benefit and cost criterion is shown:

Normalization with benefit criterion:

$$\tilde{d}_{11} = \frac{(0.8, 0.913, 0.95) \ominus (0.15, 0.187, 0.22)}{(0.95 - 0.15)}$$

$$= \frac{(0.8 - 0.22), (0.913 - 0.187), (0{,}95 - 0.15)}{(0.95 - 0.15)} = (0.725, 0.908, 1)$$

Normalization with cost criterion:

$$\tilde{d}_{51} = \frac{(11.538, 11.55, 11.562) \ominus (11.538, 11.55, 11.562)}{(25.225 - 11.538)}$$

$$= \frac{(11.538 - 11.562), (11.55 - 11.55), (11.562 - 11.538)}{(25.225 - 11.538)}$$

$$= (-0.002, 0, 0.002)$$

All the other normalization calculations were done in the same way and the results are presented in table 6.7.

6.1.4 Calculation of $\tilde{S}_j$, $\tilde{R}_j$ and $\tilde{Q}_j$ Values

$\tilde{S}_j$ and $\tilde{R}_j$ values computed were using equation 5.8 and 5.9 with the data listed in table 6.7. For $\tilde{Q}_j$ value, 5.11 was used and v value was estimated as 0,52 utilizing the formula in step 4. Examples of calculation method were presented for fuzzy S, R and Q values. All the results of the computations are placed in Table 6.8.

Table 6.6: Fuzzy best and worst values of the alternatives

	Fuzzy Best Value			Fuzzy Worst Value		
	l	m	r	l	m	r
C_1	0.8	0.913	0.95	0.15	0.1866	0.22
C_2	7.25	8.25	9.25	3.25	4.25	5.25
C_3	7	8.125	9.25	6.25	7.375	8.5
C_4	293706	294000	294294	44580.375	44625	44669.625
C_5	11.538	11.55	11.561	25.174	25.2	25.225
C_6	587.412	588	588.588	0.209	0.21	0.21
C_7	77.922	78	78.078	0.066	0.066	0.066
C_8	51.398	51.45	51.501	26.224	26.25	26.276
C_9	58741.2	58800	58858.8	3978.667	3982.65	3986.633
C_{10}	27.939	27.967	27.995	7.343	7.35	7.357
C_{11}	17.607	17.625	17.643	71.082	71.153	71.224
C_{12}	0.688	0.689	0.69	2.270	2.272	2.275
C_{13}	5.245	5.25	5.255	10.49	10.5	10.511
C_{14}	14.685	14.7	14.715	5.769	5.775	5.781
C_{15}	3.409	3.413	3.416	13.636	13.65	13.664
C_{16}	52.448	52.5	52.553	7.343	7.35	7.357
C_{17}	6	26	124	13	85	731
C_{18}	7.84	7.848	7.856	0.895	0.896	0.897
C_{19}	7.5	8.5	9.5	2.75	3.875	5
C_{20}	7.25	8.375	9.5	3.75	4.875	6
C_{21}	7.75	8.75	9.75	1.75	2.75	3.75
C_{22}	5.75	6.75	7.75	3	4	5

$$\tilde{S}_1 = [(0.775, 0.875, 0.975) \otimes (0.725, 0.908, 1)] \oplus \ldots \ldots \ldots . \oplus [(0.375, 0.488, 0.6) \otimes (-0.421, 0, 0.421)] = (0.562, 0.795, 0.975) \oplus \ldots \ldots \ldots \oplus (-0.158, 0, 0.253) = (3.178, 5.846, 9.641)$$

$$\tilde{R}_1 = MAX_1([(0.775, 0.875, 0.975) \otimes (0.725, 0.908, 1)], \ldots ., [(0.375, 0.488, 0.6) \otimes (-0.421, 0, 0.421)] = (0.562, 0.795, 0.975), \ldots \ldots \ldots, (-0.158, 0, 0.253) = (0.748, 0.849, 0.9)$$

$$v = (22 + 1)/44 = 0.52$$

Table 6.7: Normalized fuzzy difference values of alternatives

Criteria	SE	WE	HE	LFG-E
C_1	(0.725, 0.908, 1)	(0.5, 0.779, 0.875)	(0.375, 0.687, 0.813)	(-0.188, 0, 0.188)
C_2	(-0.208, 0.125, 0.458)	(-0.208, 0.125, 0.458)	(-0.333, 0, 0.333)	(0.333, 0.667, 1)
C_3	(-0.667, 0.042, 0.75)	(-0.75, 0, 0.75)	(-0.5, 0.25, 1)	(-0.583, 0.167, 0.917)
C_4	(0.997, 0.999, 1)	(0.855, 0.857, 0.858)	(0.955, 0.957, 0.958)	(-0.002, 0, 0.002)
C_5	(-0.002, 0, 0.002)	(0.228, 0.23, 0.232)	(0.995, 0.997, 1)	(0.075, 0.077, 0.078)
C_6	(0.781, 0.783, 0.784)	(0.985, 0.986, 0.987)	(0.998, 0.999, 1)	(-0.002, 0, 0.002)
C_7	(-0.002, 0, 0.002)	(0.958, 0.959, 0.961)	(0.998, 0.999, 1)	(0.056, 0.058, 0.06)
C_8	(0.786, 0.789, 0.793)	(0.994, 0.997, 1)	(-0.004, 0, 0.004)	(0.578, 0.582, 0.585)
C_9	(-0.002, 0, 0.002)	(0.151, 0.153, 0.155)	(0.161, 0.163, 0.165)	(0.998, 0.999, 1)
C_{10}	(0.634, 0.636, 0.638)	(0.997, 0.998, 1)	(-0.003, 0, 0.003)	(0.676, 0.678, 0.68)
C_{11}	(0.997, 0.998, 1)	(0.878, 0.879, 0.881)	(0.737, 0.738, 0.74)	(-0.001, 0, 0.001)
C_{12}	(0.11, 0.111, 0.112)	(-0.001, 0, 0.001)	(0.996, 0.998, 1)	(0.274, 0.275, 0.276)
C_{13}	(0.396, 0.399, 0.401)	(0.994, 0.997, 1)	(0.994, 0.997, 1)	(-0.002, 0, 0.002)
C_{14}	(0.114, 0.117, 0.121)	(0.878, 0.88, 0.883)	(0.995, 0.998, 1)	(-0.003, 0, 0.003)
C_{15}	(-0.001, 0, 0.001)	(0.403, 0.404, 0.406)	(0.997, 0.998, 1)	(0.178, 0.179, 0.18)
C_{16}	(0.928, 0.929, 0.93)	(0.997, 0.999, 1)	(0.602, 0.604, 0.606)	(-0.002, 0, 0.002)
C_{17}	(-0.153, 0.081, 1)	(-0.163, 0, 0.163)	(-0.168, 0, 0.319)	(-0.157, 0.026, 0.131)
C_{18}	(0.997, 0.999, 1)	(0.997, 0.999, 1)	(0.997, 0.999, 1)	(-0.002, 0, 0.002)
C_{19}	(-0.296, 0, 0.296)	(-0.185, 0.111, 0.407)	(0.37, 0.685, 1)	(0.111, 0.426, 0.741)
C_{20}	(-0.391, 0, 0.391)	(-0.217, 0.174, 0.565)	(0.217, 0.609, 1)	(0, 0.391, 0.783)
C_{21}	(-0.25, 0, 0.25)	(0.344, 0.594, 0.844)	(0.5, 0.75, 1)	(0.219, 0.469, 0.719)
C_{22}	(-0.421, 0, 0.421)	(-0.316, 0.132, 0.579)	(-0.053, 0.395, 0.842)	(0.158, 0.579, 1)

$$\tilde{Q}_1 = 0.52\frac{[(3.178, 5.846, 9.641) \ominus (1.710, 4.137, 7.096)]}{13.778 - 1.710} +$$

$$\frac{(1 - 0.52)[(0.748, 0.849, 0.975) \ominus (0.732, 0.832, 0.933)]}{0.975 - 0.732}$$

$$= (0.534, 0.106, 0.822)$$

Table 6.8: Fuzzy S, R and Q values of the alternatives

	$\tilde{S}_j$	$\tilde{R}_j$	$\tilde{Q}_j$
SE	(3.178, 5.846, 9.641)	(0.748, 0.849, 0.975)	(-0.534, 0.106, 0.822)
WE	(5.507, 8.724, 12.38)	(0.748, 0.849, 0.95)	(-0.434, 0.266, 0.89)
HE	(6.312, 9.754, 13.778)	(0.748, 0.849, 0.95)	(-0.399, 0.275, 0.951)
LFG-E	(1.71, 4.137, 7.096)	(0.732, 0.832, 0.933)	(-0.63, 0, 0.63)

6.1.5 Defuzzification and Ranking the Alternatives

This study adopts the defuzzification method given as a formula in step 5 to obtain crisp scores of fuzzy numbers. We obtained table 6.9 showing the crisp score of S, R and Q values and ranked list of alternatives based on their crisp scores. Consequently, there are three ranking lists of alternatives and fourth alternative that is LFG power plants is in the first order in each ranking list.

According to the result of fuzzy VIKOR application, LFG is the best performing option among the alternatives. Q value of first and second alternative is 0 and 0.125 respectively and our DQ value is 0.33. According to the methodology the difference of Q values of first and second alternative should be less than the threshold DQ. Therefore, the results do not satisfy condition one in VIKOR methodology, which states there is a considerable difference “acceptable advantage” between the alternatives. It means that LFG is still our best compromise solution; on the other hand selection of LFG among the alternatives as a sustainable energy resource does not far outweigh the other alternatives. Rests of the alternatives too are in the set of compromise solutions and a decision maker may prefer one of them.

$$Crisp(\tilde{S}_1) = \frac{2(5.846) + 3.178 + 9.641}{4} = 6.128$$

$$Crisp(\tilde{R}_1) = \frac{2(0.849) + 0.748 + 0.975}{4} = 0.855$$

$$Crisp(\tilde{Q}_1) = \frac{2(0.106) - 0.534 + 0.822}{4} = 0.125$$

Table 6.9: Q, S and R ranking list of alternatives

	Crisp Scores			Ranking		
Alternatives	Q	S	R	$\{A\}_Q$	$\{A\}_S$	$\{A\}_R$
SE	0.125	6.128	0.855	2	2	3
WE	0.247	8.834	0.849	3	3	2
HE	0.275	9.899	0.849	4	4	2
LFG-E	0	4.27	0.832	1	1	1

6.1.6 Categorical Analysis of the Alternatives

We want to learn the performance of the alternatives separately by technical, economical and environmental aspects. Technical criteria are from C_1 to C_9, economical is from C_{10} to C_{16} and environmental C_{17} to C_{22}. Same calculation steps of VIKOR technique were applied on corresponding criteria and ranks of the alternatives were obtained in three aspects.

According to VIKOR technique application, LFG-E is the best alternative. Here we observe that LFG-E is in the first place in terms of three aspects. It shows the consistency of VIKOR application result. Similarly, HE always takes the last place in the technical, economical and environmental rank. Solar energy is the second best alternative. However it falls in the third order in technical category, wind energy is placed in the second order. A decision maker who puts great emphasize on technical performance may select wind energy type when compared to solar energy.

Table 6.10: Fuzzy S, R and Q values of the alternatives in technical aspect

Technical	$\tilde{S}_j$	$\tilde{R}_j$	$\tilde{Q}_j$
SE	(1.438, 2.722, 4.173)	(0.698, 0.799, 0.975)	(-0.441, 0.2, 0.881)
WE	(1.886, 3.448, 5.116)	(0.599, 0.71, 0.853)	(-0.503, 0.186, 0.854)
HE	(1.519, 3.119, 4.828)	(0.669, 0.765, 0.925)	(-0.466, 0.21, 0.904)
LFG-E	(0.778, 1.982, 3.45)	(0.732, 0.832, 0.933)	(-0.484, 0.146, 0.739)

Table 6.11: Crisp scores and technical rank of the alternatives

	Crisp Scores			Technical
Alternatives	Q	S	R	Rank
SE	0.21	2.764	0.818	3
WE	0.181	3.475	0.718	2
HE	0.215	3.146	0.781	4
LFG-E	0.137	2.048	0.832	1

Table 6.12: Fuzzy S, R and Q values of the alternatives in economical aspect

Economical	$\tilde{S}_j$	$\tilde{R}_j$	$\tilde{Q}_j$
SE	(1.854, 2.21, 2.569)	(0.723, 0.836, 0.95)	(0.219, 0.455, 0.691)
WE	(3.209, 3.774, 4.341)	(0.698, 0.799, 0.9)	(0.395, 0.65, 0.905)
HE	(3.51, 4.095, 4.683)	(0.747, 0.848, 0.95)	(0.483, 0.742, 1)
LFG-E	(0.787, 0.91, 1.036)	(0.473, 0.542, 0.612)	(-0.162, 0, 0.162)

Table 6.13: Crisp scores and economical rank of the alternatives

	Crisp Scores			Economical
Alternatives	Q	S	R	Rank
SE	0.455	2.211	0.836	2
WE	0.65	3.775	0.799	3
HE	0.742	4.096	0.848	4
LFG-E	0	0.911	0.542	1

Table 6.14: Fuzzy S, R and Q values of the alternatives in environmental aspect

Environmental	$\tilde{S}_j$	$\tilde{R}_j$	$\tilde{Q}_j$
SE	(0.115, 0.913, 2.898)	(0.748, 0.849, 0.95)	(-0.377, 0.243, 0.829)
WE	(0.412, 1.502, 2.923)	(0.748, 0.849, 0.95)	(-0.307, 0.321, 0.822)
HE	(1.284, 2.54, 4.267)	(0.748, 0.849, 0.95)	(-0.191, 0.458, 1)
LFG-E	(0.144, 1.245, 2.61)	(0.109, 0.362, 0.704)	(-0.661, 0.044, 0.658)

Table 6.15: Crisp scores and environmental rank of the alternatives

	Crisp Scores			Environmental
Alternatives	Q	S	R	Rank
SE	0.235	1.152	0.849	2
WE	0.289	1.584	0.849	3
HE	0.431	2.658	0.849	4
LFG-E	0.021	1.311	0.384	1

6.2 Application of Fuzzy TODIM Technique

6.2.1 Determination of Criteria Weight and Performance Values of the Alternatives

In this section we will apply a different technic TODIM to the same case. Criteria weighting and performance rating are mutual phases in both technics. Therefore we can use the criteria weights and performance rating values calculated in VIKOR technic application.

Our data is in different units thus we need to normalize performance values by using equation 5.17 and 5.18. An example of normalization in terms of benefit and cost criterion is shown:

For benefit criterion:

$$\tilde{r}_{11} = \left(\frac{0.15}{0.95}, \frac{0.187}{0.95}, \frac{0.22}{0.95}\right) = (0.158, 0.196, 0.232)$$

For cost criterion:

$$\tilde{r}_{15} = \left(\frac{11.538}{11.562}, \frac{11.538}{11.55}, \frac{11.538}{11.538}\right) = (0.998, 0.99, 1)$$

After this standardization process we constructed normalized performance matrix. It is shown in table 6.16.

6.2.2 Defuzzification of Fuzzy Criteria Weights

Fuzzy criteria weights given in table 6.3 were deffuzificated by using equation 5.19-5.20 and obtained crisp weights were normalized by using equation 5.22. The results are presented in table 6.17. In the following, examples of the calculations are given.

$$V(\tilde{C}_1) = 0.875\left\{0.5\left[\frac{0.975 - 0.175}{0.975 - 0.175 + 0.975 - 0.875}\right] + (1 - 0.5)\left[1 - \frac{0.975 - 0.775}{0.975 - 0.175 + 0.875 - 0.775}\right]\right\} = 0.729$$

$$\sum_{j=1}^{22} V(\tilde{C}_j) = 0.729 + 0.618 + \cdots + 0.197 = 11.147$$

$$w_1 = \frac{0.729}{11.147} = 0.065$$

Table 6.16: Normalized performance matrix of TODIM

	SE	WE	HE	LFG-E
C_1	(0.158, 0.196, 0.232)	(0.263, 0.305, 0.421)	(0.316, 0.383, 0.526)	(0.842, 0.961, 1)
C_2	(0.703, 0.811, 0.919)	(0.703, 0.811, 0.919)	(0.784, 0.892, 1)	(0.351, 0.459, 0.568)
C_3	(0.757, 0.865, 0.973)	(0.757, 0.878, 1)	(0.676, 0.797, 0.919)	(0.703, 0.824, 0.946)
C_4	(0.151, 0.152, 0.152)	(0.272, 0.272, 0.272)	(0.187, 0.187, 0.188)	(0.998, 0.999, 1)
C_5	(0.998, 0.999, 1)	(0.784, 0.785, 0.786)	(0.457, 0.458, 0.458)	(0.915, 0.916, 0.917)
C_6	(0.216, 0.217, 0.217)	(0.014, 0.014, 0.014)	(0.0004, 0.0004, 0.0004)	(0.998, 0.999, 1)
C_7	(0.998, 0.999, 1)	(0.04, 0.04, 0.04)	(0.001, 0.001, 0.001)	(0.94, 0.941, 0.942)
C_8	(0.611, 0.612, 0.612)	(0.509, 0.51, 0.51)	(0.998, 0.999, 1)	(0.713, 0.714, 0.714)
C_9	(0.998, 0.999, 1)	(0.855, 0.856, 0.857)	(0.846, 0.847, 0.848)	(0.068, 0.068, 0.068)
C_{10}	(0.529, 0.53, 0.53)	(0.262, 0.263, 0.263)	(0.998, 0.999, 1)	(0.498, 0.499, 0.499)
C_{11}	(0.247, 0.247, 0.248)	(0.272, 0.272, 0.272)	(0.308, 0.308, 0.308)	(0.998, 0.999, 1)
C_{12}	(0.795, 0.796, 0.797)	(0.998, 0.999, 1)	(0.303, 0.303, 0.303)	(0.611, 0.612, 0.612)
C_{13}	(0.713, 0.714, 0.714)	(0.499, 0.5, 0.5)	(0.499, 0.5, 0.5)	(0.998, 0.999, 1)
C_{14}	(0.927, 0.928, 0.929)	(0.463, 0.464, 0.464)	(0.392, 0.392, 0.393)	(0.998, 0.999, 1)
C_{15}	(0.998, 0.999, 1)	(0.45, 0.451, 0.451)	(0.25, 0.25, 0.25)	(0.649, 0.649, 0.65)
C_{16}	(0.2, 0.2, 0.2)	(0.14, 0.14, 0.14)	(0.479, 0.48, 0.48)	(0.998, 0.999, 1)
C_{17}	(0.003, 0.024, 0.154)	(0.016, 0.077, 0.333)	(0.008, 0.077, 1)	(0.02, 0.044, 0.2)
C_{18}	(0.114, 0.114, 0.114)	(0.114, 0.114, 0.114)	(0.114, 0.114, 0.114)	(0.998, 0.999, 1)
C_{19}	(0.789, 0.895, 1)	(0.711, 0.816, 0.921)	(0.289, 0.408, 0.526)	(0.474, 0.592, 0.711)
C_{20}	(0.763, 0.882, 1)	(0.658, 0.776, 0.895)	(0.395, 0.513, 0.632)	(0.526, 0.645, 0.763)
C_{21}	(0.795, 0.897, 1)	(0.308, 0.41, 0.513)	(0.179, 0.282, 0.385)	(0.41, 0.513, 0.615)
C_{22}	(0.742, 0.871, 1)	(0.645, 0.79, 0.935)	(0.484, 0.629, 0.774)	(0.387, 0.516, 0.645)

Table 6.17: Defuzzificated, normalized and relative weights of the criteria

	V_j	w_j	w_{jr}
C_1	0.729	0.065	1
C_2	0.618	0.055	0.847
C_3	0.642	0.058	0.88
C_4	0.6	0.054	0.823
C_5	0.069	0.006	0.094
C_6	0.26	0.023	0.357
C_7	0.26	0.023	0.357
C_8	0.464	0.042	0.636
C_9	0.656	0.059	0.899
C_{10}	0.6	0.054	0.823
C_{11}	0.66	0.059	0.905
C_{12}	0.642	0.058	0.88
C_{13}	0.577	0.052	0.792
C_{14}	0.685	0.061	0.939
C_{15}	0.577	0.052	0.792
C_{16}	0.114	0.01	0.157
C_{17}	0.577	0.052	0.792
C_{18}	0.685	0.061	0.939
C_{19}	0.685	0.061	0.939
C_{20}	0.521	0.047	0.714
C_{21}	0.331	0.03	0.455
C_{22}	0.197	0.018	0.27

6.2.3 Calculation of Gains and Loses

After the standardization (normalization) process of the performance ratings, all criteria turned into benefit criteria features. For example before normalization, the biggest value is the best value for benefit criteria and the smallest value is the best value for cost criteria. After normalization, all criteria's best value is the biggest value of the performance ratings. Therefore gain and loss matrices were calculated according to the benefit criteria calculation method 5.24-5.25. An example of calculation are presented as follows:

$$\tilde{x}_{21} = (0.2631, 0.3052, 0.4211) > \tilde{x}_{12} = (0.1579, 0.1964, 0.2316)$$

$$d(\tilde{x}_{21}, \tilde{x}_{12}) = \sqrt{\frac{1}{3}[(0.2632 - 0.1579)^2 + (0.3052 - 0.1964)^2 + (0.4211 - 0.2316)^2]}$$

$$= 0.1400$$

$G_{21}^{1} = 0.1400$, $L_{21}^{1} = 0$ and $L_{12}^{1} = -0.1400$

$$G_1 = \begin{vmatrix} 0 & 0 & 0 & 0 \\ 0.1400 & 0 & 0 & 0 \\ 0.2210 & 0.0814 & 0 & 0 \\ 0.7402 & 0.6058 & 0.5280 & 0 \end{vmatrix}$$

$$L_1 = \begin{vmatrix} 0 & -0.1400 & -0.2210 & -0.7402 \\ 0 & 0 & -0.0814 & -0.6058 \\ 0 & 0 & 0 & -0.5280 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

As it can be noticed, the loss matrix is transpose of the gain matrix with minus sign. These calculations were iterated for all the 22 criteria and at the end we have 44 matrices, half of them belong to gain matrix and the other half belong to loss matrix. The matrices which aren’t given in this section are placed in Appendix A.

6.2.4 Calculation of Criteria’s Relative Weights w_{jr}

w_{jr} values were calculated using equation 5.28. The reference criterion is C_1 with the highest importance weight. The results presented in table 6.17 in the third column. An example is as follows:

$$w_{1r} = \frac{0.065}{0.065} = 1$$

6.2.5 Construction of Dominance Degree Matrix

In this study θ values are specified as 1, 2.5, 3 and 4. An example of calculations regarding to first criterion and for θ equals 1 is presented in the following:

$$\phi_{12}^{1(+)} = \sqrt{(0)(1)/(15.287)} = 0$$

$$\phi_{12}^{1(-)} = -\frac{1}{1}\sqrt{(0.14)\,(15.287)/(1)} = -1.4630$$

$$\phi_{12}^{1} = -1.4630$$

$$\phi_1 = \begin{vmatrix} 0 & -1.4630 & -1.8379 & -3.3638 \\ 0.0957 & 0 & -1.1152 & -3.0431 \\ 0.1202 & 0.0729 & 0 & -2.8409 \\ 0.2200 & 0.1991 & 0.1858 & 0 \end{vmatrix}$$

Same calculations repeated separately for rest of the criteria when θ equals 1, 2.5, 3 and 4. All the obtained matrices from the calculations are presented in Appendix B.

6.2.6 Construction of Overall Dominance Degree Matrix

Overall dominance degree matrices were constructed for each θ value as in the following formula.

$$\delta_{12} = \phi_{12}^{1} + \phi_{12}^{2} + \cdots + \phi_{12}^{22} = -1.463 + 0 + \cdots + 0.038 = -6.1786 \text{ for } \theta = 1.$$

$$\Delta_1 = \begin{vmatrix} 0 & -6.1786 & -17.5832 & -33.8932 \\ -39.4613 & 0 & -17.7152 & -53.7932 \\ -46.4521 & -28.0141 & 0 & -59.9528 \\ -28.8923 & -16.5477 & -15.4308 & 0 \end{vmatrix}$$

$$\Delta_{2.5}= \begin{vmatrix} 0 & -1.6934 & -6.0760 & -12.8445 \\ -15.5272 & 0 & -6.4835 & -20.9836 \\ -18.1072 & -10.7689 & 0 & -23.4762 \\ -10.7193 & -5.4432 & -4.8552 & 0 \end{vmatrix}$$

$$\Delta_{3}= \begin{vmatrix} 0 & -1.1950 & -4.7974 & -10.5057 \\ -12.8678 & 0 & -5.2355 & -17.3381 \\ -14.9577 & -8.8527 & 0 & -19.4232 \\ -8.7001 & -4.2094 & -3.6802 & 0 \end{vmatrix}$$

$$\Delta_{4}= \begin{vmatrix} 0 & -0.5721 & -3.1992 & -7.5823 \\ -9.5437 & 0 & -3.6755 & -12.7812 \\ -11.0209 & -6.4575 & 0 & -14.357 \\ -6.176 & -2.6671 & -2.2114 & 0 \end{vmatrix}$$

6.2.7 Calculation of Overall Values and Ranking the Alternatives

In the following the calculations were made for $\theta = 1$. Results for the other θ values were given under the sensitivity analysis in section 6.2.8. From first row of the Δ_1 matrix:

$\delta_{11} = 0$, $\delta_{12} = -6.1786$, $\delta_{13} = -17.5832$ and $\delta_{14} = -33.8932$

$\sum_{k=1}^{4} \delta_{1k} = 0 - 6.1786 - 17.5832 - 33.8932 = -57.6549$

$\sum_{k=1}^{4} \delta_{2k} = -110.9697$

$\sum_{k=1}^{4} \delta_{3k} = -134.4190$

$\sum_{k=1}^{4} \delta_{4k} = -60.8709$

As it is stated in equation 5.32:

$\xi(SE) = [(-57.6549) - (-134.4190)]/[(-57.6549) - (-134.4190)] = 1$

$\xi(WE) = 0.3055$, $\xi(HE) = 0$ and $\xi(LFG - E) = 0.9581$

According to the results rank of the alternatives for $\theta = 1$ were obtained as:
$SE > LFG - E > WE > HE$.

6.2.8 Sensitivity Analysis for TODIM

We conducted a sensitivity analysis for TODIM to see the effect of different situations on the results. In this regard, in order to analyze the influence of the parameter θ, we tried different θ values in the application. Table 6.18 shows overall value of the alternatives for each θ value and ranking lists are in table 6.19. The order of the alternatives changed at $\theta = 3$ and LFG-E and SE interchanged. This order stayed the same when θ is equal to 4.

The suggested θ interval is between 2 and 2.5 (Krohling and Souza, 2012). In this case, energy investors may base on the ranking list of $\theta = 2.5$. On the other hand, an investor who concerns and wants to prevent risk may prefer the order for $\theta = 3$ or 4.

Table 6.18: Overall value of the alternatives in different θ values

	$\theta = 1$	$\theta = 2.5$	$\theta = 3$	$\theta = 4$
$\xi(SE)$	1	1	0,3068	0,9856
$\xi(WE)$	0,3055	0,2948	0,0255	0,2809
$\xi(HE)$	0	0	0	0
$\xi(LFG - E)$	0,9581	0,9873	1	1

Table 6.19: Rank of the alternatives by θ values

θ values	Rank of the alternatives
$\theta = 1$	$SE > LFG - E > WE > HE$
$\theta = 2.5$	$SE > LFG - E > WE > HE$
$\theta = 3$	$LFG - E > SE > WE > HE$
$\theta = 4$	$LFG - E > SE > WE > HE$

The emergent shape in Fig. 6.1 has the same characteristic feature with S-shaped graph of prospect theory. In Fig. 6.1 for the gain part, x-axis represents real gain calculated by equation 5.24 and y-axis represents dominance degree for gain in equation 5.29. In a similar manner, for the loss part x-axis represents real loss calculated by equation 5.25

and y-axis represents dominance degree for lost in equation 5.30. Consequently in the graph of TODIM method x-axis is for the real gain and loss values, and y-axis reflects the effects of those gains and losses. In Fig. 6.1, we can observe that the effect of loss is more than the loss itself. This difference is decreasing as θ value increase and that is why bigger value of θ gives secure results in terms of risk.

In order to better visualize gain part of the Fig. 6.1, we drew it separately as Fig. 6.2 and concavity of the graph is apparent. Here the difference of gain and its effect is very close to each other. This situation results from prospect theory's characteristic features. For more explanation see the introduction section.

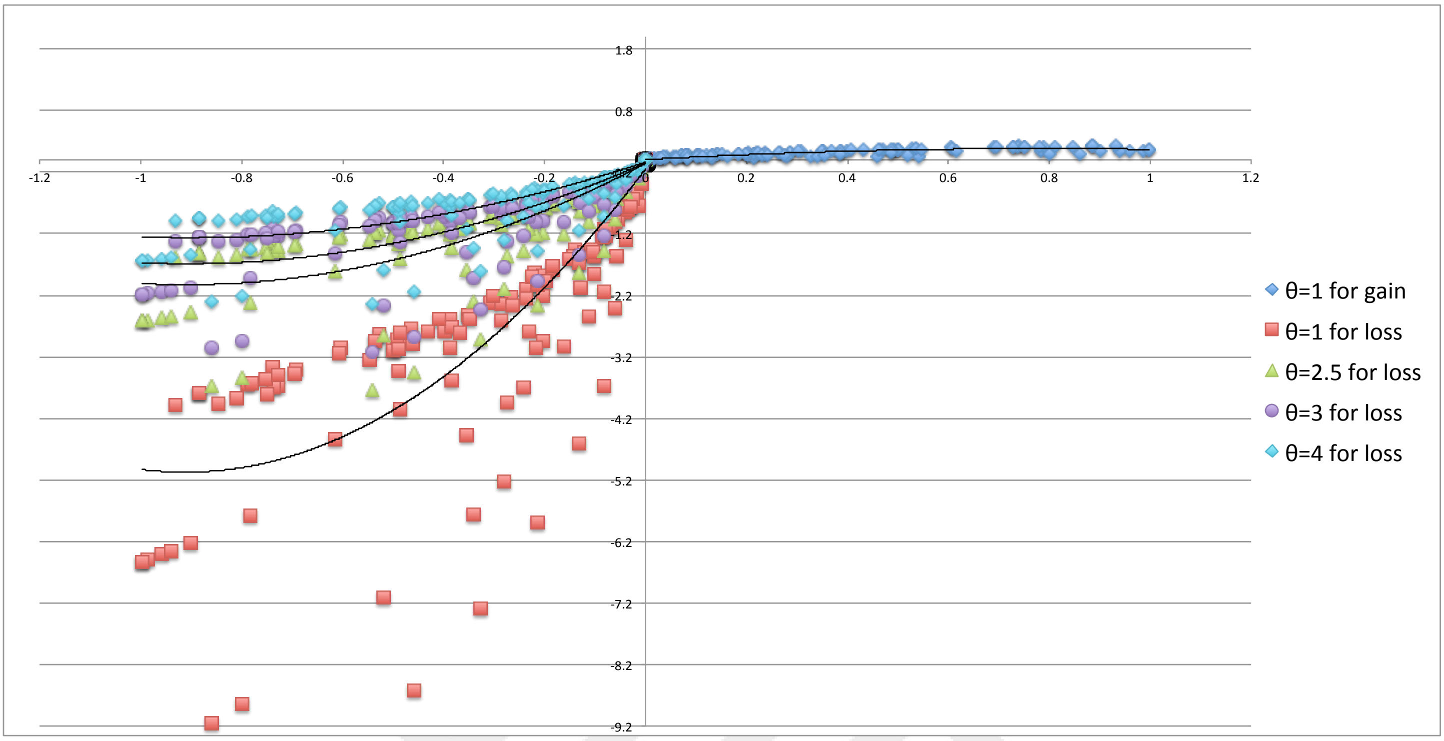

Fig. 6.1: Value function of TODIM method application with different θ values

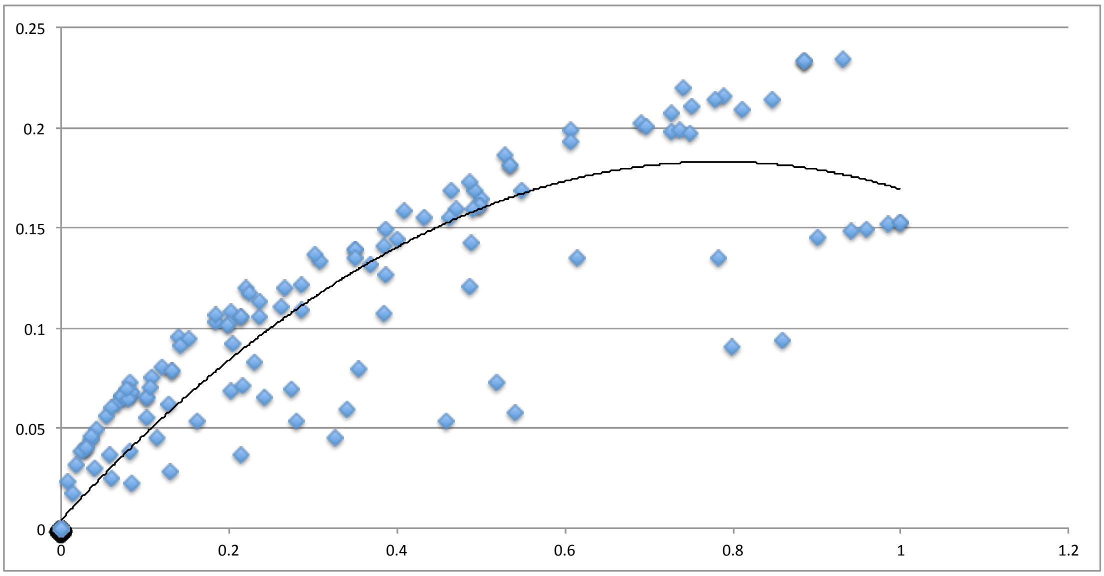

Fig. 6.2: Gain function of TODIM application

7. CONCLUSION

In this study, sustainable and renewable energy alternatives have been evaluated by fuzzy VIKOR and fuzzy TODIM methods separately. The consequence of evaluation process by fuzzy VIKOR is that LFG is the best option as a sustainable energy resource in the alternatives. The main reason for obtaining this result is that LFG power plants have performed very well in the technical, economical and environmental category. For the criteria having high importance weight such as technical efficiency and GHG emissions avoided, LFG has best performance rating most of the time. Solar energy power plants are the second best alternative but the weakness of solar energy is technical efficiency and this reflects in electricity production negatively. Wind energy performs well in terms of technical and environmental aspects however it is not very attractive economically. The worst alternative is hydraulic. Hydraulic power plants are not very environment-friendly energy production systems comparing to other renewable energy sources. Although they are effective technically and economically, hydraulic energy falls behind the other alternatives in this evaluation study.

In the evaluation with TODIM technic, the best alternative is solar energy under the normal conditions (θ equals 1 and 2.5). We can say that VIKOR and TODIM results are consistent with each other. As we stated earlier in section 5.1.4, LFG-E is the best alternative but Q values of the alternatives are close to each other, thus it doesn't have an acceptable advantage on the other alternatives. TODIM method results in LFG-E as the best energy alternative in the case of risk aversion when θ equals 3 and 4. In other words as the concern of risk increase, LFG becomes to be best alternative. According to TODIM method, an investor reluctant to deal with risk may prefer LFG-E and it satisfies the decision makers. However, to choose solar energy to invest cant be defined as a wrong decision, it also satisfies and is capable of meeting expectations. Consequently, we suggest energy investors LFG-E to invest, which reveals as the best energy alternative by VIKOR and TODIM technic and a secure option in the case of risk aversion.

VIKOR and TODIM are both multicriteria decision-making technics. Their basic principles are to rank the alternatives through specified criteria. We are able to integrate fuzzy sets into both technics successfully. Integrating fuzzy approach into the technics enables us to implement this real life case. TODIM technic provides us a pairwise comparison between the alternatives and by this means we can check gains and losses of any two alternatives regarding any criteria. TODIM method differs from VIKOR by this feature. On the other hand, VIKOR is a distance based method and ranks the alternatives accordingly. Besides ranking the alternatives, VIKOR provides a solution set and an alternative can be preferred in that set. Finally, the main difference between the technics is that TODIM adds risk factor in the system.

In this evaluation system, first three most important criteria are technical efficiency, impact on the ecosystem, GHG emissions avoided and government support rate. As a consequence technical, economical and environmental aspects of renewable energies are almost equally important and cannot be thought separately. Analyzing a power plant considering only one or two aspects of renewable energies may mislead decision makers and the results may not be reliable. We conducted this study regarding all the important criteria within technical, economical and environmental scope. This makes our results more quality and improves the reliability.

Waste creates both economical and environmental problems in the cities and LFG power plants are a smart and efficient way of eliminating and utilizing of waste while producing energy. Therefore municipalities need a comprehensive waste management policy to use LFG opportunity and so to create a sustainable environment in the cities. LFG power plants are followed by solar, wind and hydraulic alternatives.

For the further studies, a research can be conducted locally in a specific region to find out best performing alternatives regarding that area to increase utilization of renewable energy. Also, different multicriteria techniques can be integrated to the solution process if the decision makers increase in numbers. Or different sophisticated economic applications like real options can be applied in lieu of net present value.

This is a comparative study of fuzzy VIKOR and fuzzy TODIM technics. In the literature, there are many studies of VIKOR in different fields. VIKOR application papers in sustainable and renewable energy area are nearly at 8% (Mardani et al., 2015). VIKOR technic part of this comprehensive study enriches the literature. On the other hand, TODIM and fuzzy TODIM relatively new technics, there are not sufficient numbers of studies yet. Especially in terms of fuzzy TODIM, there is very limited number of papers and this study is one of the first applications of evaluation of sustainable and renewable energy systems by fuzzy TODIM. Therefore this paper may be a reference or an example paper in the next studies in the energy field for researchers.

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APPENDICES

Appendix A.

Gain and loss matrices of fuzzy TODIM method application are provided in this appendix regarding all the criteria.

$$G_1 = \begin{vmatrix} 0 & 0 & 0 & 0 \\ 0.1400 & 0 & 0 & 0 \\ 0.2210 & 0.0814 & 0 & 0 \\ 0.7402 & 0.6058 & 0.5280 & 0 \end{vmatrix}$$

$$L_1 = \begin{vmatrix} 0 & -0.1400 & -0.2210 & -0.7402 \\ 0 & 0 & -0.0814 & -0.6058 \\ 0 & 0 & 0 & -0.5280 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$G_2 = \begin{vmatrix} 0 & 0 & 0 & 0.3514 \\ 0 & 0 & 0 & 0.3514 \\ 0.0810 & 0.0810 & 0 & 0.4324 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$L_2 = \begin{vmatrix} 0 & 0 & -0.0810 & 0 \\ 0 & 0 & -0.0810 & 0 \\ 0 & 0 & 0 & 0 \\ -0.3514 & -0.3514 & -0.4324 & 0 \end{vmatrix}$$

$$G_3=\begin{vmatrix} 0 & 0 & 0.0685 & 0.0420 \\ 0.0175 & 0 & 0.0810 & 0.0541 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0.0270 & 0 \end{vmatrix}$$

$$L_3=\begin{vmatrix} 0 & -0.0175 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -0.0685 & -0.0810 & 0 & -0.0270 \\ -0.0420 & -0.0541 & 0 & 0 \end{vmatrix}$$

$$G_4=\begin{vmatrix} 0 & 0 & 0 & 0 \\ 0.1202 & 0.0846 & 0 & 0 \\ 0.0357 & 0 & 0 & 0 \\ 0.8474 & 0.7271 & 0.8117 & 0 \end{vmatrix}$$

$$L_4=\begin{vmatrix} 0 & -0.1202 & -0.0357 & -0.8474 \\ 0 & -0.0846 & 0 & -0.7271 \\ 0 & 0 & 0 & -0.8117 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$G_5=\begin{vmatrix} 0 & 0.2141 & 0.5411 & 0.0832 \\ 0 & 0 & 0.3271 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0.1308 & 0.4579 & 0 \end{vmatrix}$$

$$L_5=\begin{vmatrix} 0 & 0 & 0 & 0 \\ -0.2141 & 0 & 0 & -0.1308 \\ -0.5411 & -0.3271 & 0 & -0.4579 \\ -0.0832 & 0 & 0 & 0 \end{vmatrix}$$

$$G_6=\begin{vmatrix} 0 & 0.203 & 0.2163 & 0 \\ 0 & 0 & 0.0132 & 0 \\ 0 & 0 & 0 & 0 \\ 0.7824 & 0.9854 & 0.9986 & 0 \end{vmatrix}$$

$$L_6=\begin{vmatrix} 0 & 0 & 0 & -0.7824 \\ -0.203 & 0 & 0 & -0.9854 \\ -0.2163 & -0.0132 & 0 & -0.9986 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$G_7=\begin{vmatrix} 0 & 0.9587 & 0.9982 & 0.0576 \\ 0 & 0 & 0.0395 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0.901 & 0.9405 & 0 \end{vmatrix}$$

$$L_7=\begin{vmatrix} 0 & 0 & 0 & 0 \\ -0.9587 & 0 & 0 & -0.9010 \\ -0.9982 & -0.0395 & 0 & -0.9405 \\ -0.0576 & 0 & 0 & 0 \end{vmatrix}$$

$$G_8=\begin{vmatrix} 0 & 0.1019 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0.3874 & 0.4893 & 0 & 0.2854 \\ 0.1019 & 0.2039 & 0 & 0 \end{vmatrix}$$

$$L_8=\begin{vmatrix} 0 & 0 & -0.3874 & -0.1019 \\ -0.1019 & 0 & -0.4893 & -0.2039 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & -0.2854 & 0 \end{vmatrix}$$

$$G_9= \begin{vmatrix} 0 & 0.1427 & 0.1517 & 0.9313 \\ 0 & 0 & 0.009 & 0.7886 \\ 0 & 0 & 0 & 0.7797 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$L_9= \begin{vmatrix} 0 & 0 & 0 & 0 \\ -0.1427 & 0 & 0 & 0 \\ -0.1517 & -0.009 & 0 & 0 \\ -0.9313 & -0.7886 & -0.7797 & 0 \end{vmatrix}$$

$$G_{10}= \begin{vmatrix} 0 & 0.267 & 0 & 0.0307 \\ 0 & 0 & 0 & 0 \\ 0.4695 & 0.7365 & 0 & 0.5002 \\ 0 & 0.2363 & 0 & 0 \end{vmatrix}$$

$$L_{10}= \begin{vmatrix} 0 & 0 & -0.4695 & 0 \\ -0.2670 & 0 & -0.7365 & -0.2363 \\ 0 & 0 & 0 & 0 \\ -0.0307 & 0 & -0.5002 & 0 \end{vmatrix}$$

$$G_{11}= \begin{vmatrix} 0 & 0 & 0 & 0 \\ 0.0244 & 0 & 0 & 0 \\ 0.0604 & 0.036 & 0 & 0 \\ 0.7515 & 0.7271 & 0.6912 & 0 \end{vmatrix}$$

$$L_{11}= \begin{vmatrix} 0 & -0.0244 & -0.0604 & -0.7515 \\ 0 & 0 & -0.0360 & -0.7271 \\ 0 & 0 & 0 & -0.6912 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$G_{12}= \begin{vmatrix} 0 & 0 & 0.4931 & 0.1842 \\ 0.203 & 0 & 0.6961 & 0.3872 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0.3089 & 0 \end{vmatrix}$$

$$L_{12}= \begin{vmatrix} 0 & -0.203 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -0.4931 & -0.6961 & 0 & -0.3089 \\ -0.1842 & -0.3872 & 0 & 0 \end{vmatrix}$$

$$G_{13}= \begin{vmatrix} 0 & 0.2141 & 0.2141 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0.2854 & 0.4995 & 0.4995 & 0 \end{vmatrix}$$

$$L_{13}= \begin{vmatrix} 0 & 0 & 0 & -0.2854 \\ -0.2141 & 0 & 0 & -0.4995 \\ -0.2141 & 0 & 0 & -0.4995 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$G_{14}= \begin{vmatrix} 0 & 0.4638 & 0.5352 & 0 \\ 0 & & 0.0714 & 0 \\ 0 & 0 & 0 & 0 \\ 0.0714 & 0.5352 & 0.6065 & 0 \end{vmatrix}$$

$$L_{14}= \begin{vmatrix} 0 & 0 & 0 & -0.0714 \\ -0.4638 & 0 & 0 & -0.5352 \\ -0.5352 & -0.0714 & 0 & -0.6065 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$G_{15}=$

0	0.5481	0.7493	0.3497
0	0	0.2012	0
0	0	0	0
0	0.1984	0.3996	0

$L_{15}=$

0	0	0	0
-0.5481	0	0	-0.1984
-0.7493	-0.2012	0	-0.3996
-0.3497	0	0	0

$G_{16}=$

0	0.0599	0	0
0	0	0	0
0.2797	0.3397	0	0
0.7992	0.8591	0.5195	0

$L_{16}=$

0	0	-0.2797	-0.7992
-0.0599	0	-0.3397	-0.8591
0	0	0	-0.5195
0	0	0	0

$G_{17}=$

0	0	0	0
0.1084	0	0	0.1084
0.4895	0.3849	0	0.4623
0.0309	0	0	0

$L_{17}=$

0	-0.1084	-0.4895	-0.0309
0	0	-0.3849	0
0	0	0	0
0	-0.1084	-0.4623	0

$$G_{18}=\begin{vmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0.8849 & 0.8849 & 0.8849 & 0 \end{vmatrix}$$

$$L_{18}=\begin{vmatrix} 0 & 0 & 0 & -0.8849 \\ 0 & 0 & 0 & -0.8849 \\ 0 & 0 & 0 & -0.8849 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$G_{19}=\begin{vmatrix} 0.0790 & 0.4870 & 0.3028 & 0 \\ 0 & 0.4080 & 0.2239 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0.1842 & 0 & 0 \end{vmatrix}$$

$$L_{19}=\begin{vmatrix} -0.0790 & 0 & 0 & 0 \\ -0.4870 & -0.4080 & 0 & -0.1842 \\ -0.3028 & -0.2239 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$G_{20}=\begin{vmatrix} 0 & 0.1053 & 0.3684 & 0.2368 \\ 0 & 0 & 0.2632 & 0.1316 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0.1316 & 0 \end{vmatrix}$$

$$L_{20}=\begin{vmatrix} 0 & 0 & 0 & 0 \\ -0.1053 & 0 & 0 & 0 \\ -0.3684 & -0.2632 & 0 & -0.1316 \\ -0.2368 & -0.1316 & 0 & 0 \end{vmatrix}$$

$$G_{21}= \begin{vmatrix} 0 & 0.4872 & 0.6154 & 0.3846 \\ 0 & 0 & 0.1282 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0.1026 & 0.2308 & 0 \end{vmatrix}$$

$$L_{21}= \begin{vmatrix} 0 & 0 & 0 & 0 \\ -0.4872 & 0 & 0 & -0.1026 \\ -0.6154 & -0.1282 & 0 & -0.2308 \\ -0.3846 & 0 & 0 & 0 \end{vmatrix}$$

$$G_{22}= \begin{vmatrix} 0 & 0.0817 & 0.2423 & 0.3548 \\ 0 & 0 & 0.1613 & 0.2745 \\ 0 & 0 & 0 & 0.1137 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

$$L_{22}= \begin{vmatrix} 0 & 0 & 0 & 0 \\ -0.0817 & 0 & 0 & 0 \\ -0.2423 & -0.1613 & 0 & 0 \\ -0.3548 & -0.2745 & -0.1137 & 0 \end{vmatrix}$$

Appendix B.

In this appendix, dominance degree matrices of fuzzy TODIM application are provided regarding all criteria and different θ attenuation factor values.

Results for $\theta = 1$:

$$\phi_1 = \begin{vmatrix} 0 & -1.4630 & -1.8379 & -3.3638 \\ 0.0957 & 0 & -1.1152 & -3.0431 \\ 0.1202 & 0.0729 & 0 & -2.8409 \\ 0.2200 & 0.1991 & 0.1858 & 0 \end{vmatrix}$$

$$\phi_2 = \begin{vmatrix} 0 & 0 & -1.2096 & 0.1395 \\ 0 & 0 & -1.2096 & 0.1395 \\ 0.067 & 0.067 & 0 & 0.1548 \\ -2.518 & -2.518 & -2.7935 & 0 \end{vmatrix}$$

$$\phi_3 = \begin{vmatrix} 0 & -0.5505 & 0.0628 & 0.0492 \\ 0.0317 & 0 & 0.0683 & 0.0559 \\ -1.0906 & -1.1868 & 0 & -0.6852 \\ -0.8543 & -0.969 & 0.0394 & 0 \end{vmatrix}$$

$$\phi_4 = \begin{vmatrix} 0 & -1.4946 & -0.8142 & -3.9677 \\ 0.0804 & 0 & 0.0675 & -3.6755 \\ 0.0438 & -1.2534 & 0 & -3.8833 \\ 0.2136 & 0.1978 & 0.209 & 0 \end{vmatrix}$$

$$\phi_5 = \begin{vmatrix} 0 & 0.0363 & 0.0578 & 0.0227 \\ -5.8915 & 0 & 0.0449 & -4.6056 \\ -9.3668 & -7.2821 & 0 & -8.6162 \\ -3.674 & 0.0284 & 0.0531 & 0 \end{vmatrix}$$

$$\phi_6 = \begin{vmatrix} 0 & 0.0688 & 0.071 & -5.7917 \\ -2.9503 & 0 & 0.0176 & -6.4998 \\ -3.045 & -0.7534 & 0 & -6.5433 \\ 0.1351 & 0.1516 & 0.1526 & 0 \end{vmatrix}$$

$$\phi_7 = \begin{vmatrix} 0 & 0.1495 & 0.1526 & 0.0367 \\ -6.411 & 0 & 0.0304 & -6.2153 \\ -6.5417 & -1.3014 & 0 & -6.3501 \\ -1.5719 & 0.145 & 0.1481 & 0 \end{vmatrix}$$

$$\phi_8 = \begin{vmatrix} 0 & 0.0651 & -3.0519 & -1.5656 \\ -1.5656 & 0 & -3.43 & -2.2141 \\ 0.1269 & 0.1427 & 0 & 0.109 \\ 0.0651 & 0.0921 & -2.6197 & 0 \end{vmatrix}$$

$$\phi_9 = \begin{vmatrix} 0 & 0.0916 & 0.0945 & 0.2341 \\ -1.5574 & 0 & 0.0230 & 0.2154 \\ -1.6056 & -0.3905 & 0 & 0.2142 \\ -3.9786 & -3.6611 & -3.6402 & 0 \end{vmatrix}$$

$$\phi_{10} = \begin{vmatrix} 0 & 0.1199 & -2.9534 & 0.0406 \\ -2.227 & 0 & -3.6989 & -2.0952 \\ 0.1590 & 0.1991 & 0 & 0.1641 \\ -0.7548 & 0.1128 & -3.0483 & 0 \end{vmatrix}$$

$$\phi_{11} = \begin{vmatrix} 0 & -0.6423 & -1.010 & -3.5636 \\ 0.0380 & 0 & -0.7794 & -3.5053 \\ 0.0598 & 0.0461 & 0 & -3.4175 \\ 0.2109 & 0.2074 & 0.2022 & 0 \end{vmatrix}$$

$$\phi_{12} = \begin{vmatrix} 0 & -1.878 & 0.1685 & 0.1030 \\ 0.1081 & 0 & 0.2002 & 0.1493 \\ -2.9267 & -3.4775 & 0 & -2.3166 \\ -1.7887 & -2.5935 & 0.1333 & 0 \end{vmatrix}$$

$$\phi_{13} = \begin{vmatrix} 0 & 0.1053 & 0.1053 & -2.348 \\ -2.0334 & 0 & 0 & -3.106 \\ -2.0334 & 0 & 0 & -3.106 \\ 0.1216 & 0.1608 & 0.1608 & 0 \end{vmatrix}$$

$$\phi_{14} = \begin{vmatrix} 0 & 0.1688 & 0.1813 & -1.0778 \\ -2.7479 & 0 & 0.0662 & -2.9517 \\ -2.9517 & -1.0778 & 0 & -3.1423 \\ 0.0662 & 0.1813 & 0.1930 & 0 \end{vmatrix}$$

$$\phi_{15} = \begin{vmatrix} 0 & 0.1685 & 0.197 & 0.1345 \\ -3.2535 & 0 & 0.1021 & -1.9576 \\ -3.8041 & -1.9712 & 0 & -2.7781 \\ -2.5987 & 0.1014 & 0.1438 & 0 \end{vmatrix}$$

$$\phi_{16} = \begin{vmatrix} 0 & 0.0248 & -5.227 & -8.8352 \\ -2.4196 & 0 & -5.7598 & -9.1605 \\ 0.0535 & 0.0590 & 0 & -7.1231 \\ 0.0905 & 0.0938 & 0.0729 & 0 \end{vmatrix}$$

$$\phi_{17} = \begin{vmatrix} 0 & -1.4469 & -3.0748 & -0.7722 \\ 0.0749 & 0 & -2.7266 & 0.0641 \\ 0.1592 & 0.1412 & 0 & 0.1547 \\ 0.04 & -1.2373 & -2.9882 & 0 \end{vmatrix}$$

$$\phi_{18} = \begin{vmatrix} 0 & 0 & 0 & -3.7956 \\ 0 & 0 & 0 & -3.7956 \\ 0 & 0 & 0 & -3.7956 \\ 0.2331 & 0.2331 & 0.2331 & 0 \end{vmatrix}$$

$$\phi_{19} = \begin{vmatrix} 0 & 0.0696 & 0.1730 & 0.1364 \\ -1.1337 & 0 & 0.1583 & 0.1173 \\ -2.8156 & -2.5773 & 0 & -1.7317 \\ -2.2203 & -1.9094 & 0.1064 & 0 \end{vmatrix}$$

$$\phi_{20} = \begin{vmatrix} 0 & 0.0701 & 0.1312 & 0.1052 \\ -1.501 & 0 & 0.1109 & 0.0784 \\ -2.808 & -2.3732 & 0 & -1.6781 \\ -2.2514 & -1.6781 & 0.0784 & 0 \end{vmatrix}$$

$$\phi_{21} = \begin{vmatrix} 0 & 0.1204 & 0.1353 & 0.1069 \\ -4.0479 & 0 & 0.0617 & -1.8573 \\ -4.5495 & -2.0766 & 0 & -2.786 \\ -3.5967 & 0.0552 & 0.0828 & 0 \end{vmatrix}$$

$$\phi_{22} = \begin{vmatrix} 0 & 0.038 & 0.0654 & 0.0792 \\ -2.1503 & 0 & 0.0534 & 0.0697 \\ -3.7027 & -3.021 & 0 & 0.0448 \\ -4.4808 & -3.9411 & -2.5361 & 0 \end{vmatrix}$$

Results for $\boldsymbol{\theta = 2.5}$:

$$\phi_1 = \begin{vmatrix} 0 & -0.5852 & -0.7352 & -1.3455 \\ 0.0957 & 0 & -0.4461 & -1.2172 \\ 0.1202 & 0.0729 & 0 & -1.1364 \\ 0.22 & 0.1991 & 0.1858 & 0 \end{vmatrix}$$

$$\phi_2 = \begin{vmatrix} 0 & 0 & -0.4838 & 0.1395 \\ 0 & 0 & -0.4838 & 0.1395 \\ 0.067 & 0.067 & 0 & 0.1548 \\ -1.0072 & -1.0072 & -1.1174 & 0 \end{vmatrix}$$

$$\phi_3 = \begin{vmatrix} 0 & -0.2202 & 0.0628 & 0.0492 \\ 0.0317 & 0 & 0.0683 & 0.0558 \\ -0.4362 & -0.4747 & 0 & -0.2741 \\ -0.3417 & -0.3876 & 0.0394 & 0 \end{vmatrix}$$

$$\phi_4 = \begin{vmatrix} 0 & -0.5978 & -0.3257 & -1.5871 \\ 0.0804 & 0 & 0.0675 & -1.4702 \\ 0.0438 & -0.5014 & 0 & -1.5533 \\ 0.2136 & 0.1978 & 0.209 & 0 \end{vmatrix}$$

$$\phi_5 = \begin{vmatrix} 0 & 0.0363 & 0.0578 & 0.0227 \\ -2.3566 & 0 & 0.0449 & -1.8422 \\ -3.7467 & -2.9128 & 0 & -3.4465 \\ -1.4696 & 0.0284 & 0.0531 & 0 \end{vmatrix}$$

$$\phi_6 = \begin{vmatrix} 0 & 0.0688 & 0.071 & -2.3167 \\ -1.1801 & 0 & 0.0176 & -2.5999 \\ -1.218 & -0.3013 & 0 & -2.6173 \\ 0.1351 & 0.1516 & 0.1526 & 0 \end{vmatrix}$$

$$\phi_7 = \begin{vmatrix} 0 & 0.1495 & 0.1526 & 0.0367 \\ -2.5644 & 0 & 0.0304 & -2.4861 \\ -2.6167 & -0.5205 & 0 & -2.5400 \\ -0.6288 & 0.1450 & 0.1481 & 0 \end{vmatrix}$$

$$\phi_8 = \begin{vmatrix} 0 & 0.0651 & -1.2207 & -0.6262 \\ -0.6262 & 0 & -1.3720 & -0.8856 \\ 0.1269 & 0.1427 & 0 & 0.1090 \\ 0.0651 & 0.0921 & -1.0479 & 0 \end{vmatrix}$$

$$\phi_9 = \begin{vmatrix} 0 & 0.0916 & 0.0945 & 0.2341 \\ -0.623 & 0 & 0.023 & 0.2154 \\ -0.6423 & -0.1562 & 0 & 0.2142 \\ -1.5914 & -1.4644 & -1.4561 & 0 \end{vmatrix}$$

$$\phi_{10} = \begin{vmatrix} 0 & 0.1199 & -1.1814 & 0.0406 \\ -0.8908 & 0 & -1.4796 & -0.8381 \\ 0.159 & 0.1991 & 0 & 0.1641 \\ -0.3019 & 0.1128 & -1.2193 & 0 \end{vmatrix}$$

$$\phi_{11} = \begin{vmatrix} 0 & -0.2569 & -0.404 & -1.4255 \\ 0.038 & 0 & -0.3118 & -1.4021 \\ 0.0598 & 0.0461 & 0 & -1.367 \\ 0.2109 & 0.2074 & 0.2022 & 0 \end{vmatrix}$$

$$\phi_{12} = \begin{vmatrix} 0 & -0.7512 & 0.1685 & 0.1030 \\ 0.1081 & 0 & 0.2002 & 0.1493 \\ -1.1707 & -1.3910 & 0 & -0.9266 \\ -0.7155 & -1.0374 & 0.1333 & 0 \end{vmatrix}$$

$$\phi_{13} = \begin{vmatrix} 0 & 0.1053 & 0.1053 & -0.9392 \\ -0.8134 & 0 & 0 & -1.2424 \\ -0.8134 & 0 & 0 & -1.2424 \\ 0.1216 & 0.1608 & 0.1608 & 0 \end{vmatrix}$$

$$\phi_{14} = \begin{vmatrix} 0 & 0.1688 & 0.1813 & -0.4311 \\ -1.0992 & 0 & 0.0662 & -1.1807 \\ -1.1807 & -0.4311 & 0 & -1.2569 \\ 0.0662 & 0.1813 & 0.1930 & 0 \end{vmatrix}$$

$$\phi_{15} = \begin{vmatrix} 0 & 0.1685 & 0.1970 & 0.1345 \\ -1.3014 & 0 & 0.1021 & -0.783 \\ -1.5216 & -0.7885 & 0 & -1.1113 \\ -1.0395 & 0.1014 & 0.1438 & 0 \end{vmatrix}$$

$$\phi_{16} = \begin{vmatrix} 0 & 0.0248 & -2.0908 & -3.5341 \\ -0.9678 & 0 & -2.3039 & -3.6642 \\ 0.0535 & 0.0590 & 0 & -2.8493 \\ 0.0905 & 0.0938 & 0.0729 & 0 \end{vmatrix}$$

$$\phi_{17} = \begin{vmatrix} 0 & -0.5788 & -1.2299 & -0.3089 \\ 0.0749 & 0 & -1.0907 & 0.0641 \\ 0.1592 & 0.1412 & 0 & 0.1547 \\ 0.0400 & -0.4949 & -1.1953 & 0 \end{vmatrix}$$

$$\phi_{18} = \begin{vmatrix} 0 & 0 & 0 & -1.5182 \\ 0 & 0 & 0 & -1.5182 \\ 0 & 0 & 0 & -1.5182 \\ 0.2331 & 0.2331 & 0.2331 & 0 \end{vmatrix}$$

$$\phi_{19} = \begin{vmatrix} 0 & 0.0696 & 0.1730 & 0.1364 \\ -0.4535 & 0 & 0.1583 & 0.1173 \\ -1.1262 & -1.0309 & 0 & -0.6927 \\ -0.8881 & -0.7638 & 0.1064 & 0 \end{vmatrix}$$

$$\phi_{20} = \begin{vmatrix} 0 & 0.0701 & 0.1312 & 0.1052 \\ -0.6004 & 0 & 0.1109 & 0.0784 \\ -1.1232 & -0.9493 & 0 & -0.6713 \\ -0.9006 & -0.6713 & 0.0784 & 0 \end{vmatrix}$$

$$\phi_{21} = \begin{vmatrix} 0 & 0.1204 & 0.1353 & 0.1069 \\ -1.6192 & 0 & 0.0617 & -0.7429 \\ -1.8198 & -0.8306 & 0 & -1.1144 \\ -1.4387 & 0.0552 & 0.0828 & 0 \end{vmatrix}$$

$$\phi_{22} = \begin{vmatrix} 0 & 0.038 & 0.0654 & 0.0792 \\ -0.8601 & 0 & 0.0534 & 0.0697 \\ -1.4811 & -1.2084 & 0 & 0.0448 \\ -1.7923 & -1.5765 & -1.0144 & 0 \end{vmatrix}$$

Results for $\theta = 3$:

$$\phi_1 = \begin{vmatrix} 0 & -0.4877 & -0.6126 & -1.1213 \\ 0.0957 & 0 & -0.3717 & -1.0144 \\ 0.1202 & 0.0729 & 0 & -0.9470 \\ 0.2200 & 0.1991 & 0.1858 & 0 \end{vmatrix}$$

$$\phi_2 = \begin{vmatrix} 0 & 0 & -0.4032 & 0.1395 \\ 0 & 0 & -0.4032 & 0.1395 \\ 0.0670 & 0.0670 & 0 & 0.1548 \\ -0.8393 & -0.8393 & -0.9312 & 0 \end{vmatrix}$$

$$\phi_3 = \begin{vmatrix} 0 & -0.1835 & 0.0628 & 0.0492 \\ 0.0317 & 0 & 0.0683 & 0.0558 \\ -0.3635 & -0.3956 & 0 & -0.2284 \\ -0.2848 & -0.3230 & 0.0394 & 0 \end{vmatrix}$$

$$\phi_4 = \begin{vmatrix} 0 & -0.4982 & -0.2714 & -1.3226 \\ 0.0804 & 0 & 0.0675 & -1.2252 \\ 0.0438 & -0.4178 & 0 & -1.2944 \\ 0.2136 & 0.1978 & 0.2090 & 0 \end{vmatrix}$$

$$\phi_5 = \begin{vmatrix} 0 & 0.0363 & 0.0578 & 0.0227 \\ -1.9638 & 0 & 0.0449 & -1.5352 \\ -3.1223 & -2.4274 & 0 & -2.8721 \\ -1.2247 & 0.0284 & 0.0531 & 0 \end{vmatrix}$$

$$\phi_6 = \begin{vmatrix} 0 & 0.0688 & 0.0710 & -1.9306 \\ -0.9834 & 0 & 0.0176 & -2.1666 \\ -1.015 & -0.2511 & 0 & -2.1811 \\ 0.1351 & 0.1516 & 0.1526 & 0 \end{vmatrix}$$

$$\phi_7 = \begin{vmatrix} 0 & 0.1495 & 0.1526 & 0.0367 \\ -2.1370 & 0 & 0.0304 & -2.0718 \\ -2.1806 & -0.4338 & 0 & -2.1167 \\ -0.524 & 0.1450 & 0.1481 & 0 \end{vmatrix}$$

$$\phi_8 = \begin{vmatrix} 0 & 0.0651 & -1.0173 & -0.5219 \\ -0.5219 & 0 & -1.1433 & -0.7380 \\ 0.1269 & 0.1427 & 0 & 0.1090 \\ 0.0651 & 0.0921 & -0.8732 & 0 \end{vmatrix}$$

$$\phi_9 = \begin{vmatrix} 0 & 0.0916 & 0.0945 & 0.2341 \\ -0.5191 & 0 & 0.0230 & 0.2154 \\ -0.5352 & -0.1302 & 0 & 0.2142 \\ -1.3262 & -1.2204 & -1.2134 & 0 \end{vmatrix}$$

$$\phi_{10} = \begin{vmatrix} 0 & 0.1199 & -0.9845 & 0.0406 \\ -0.7423 & 0 & -1.233 & -0.6984 \\ 0.1590 & 0.1991 & 0 & 0.1641 \\ -0.2516 & 0.1128 & -1.0161 & 0 \end{vmatrix}$$

$$\phi_{11} = \begin{vmatrix} 0 & -0.2141 & -0.3367 & -1.1879 \\ 0.0380 & 0 & -0.2598 & -1.1684 \\ 0.0598 & 0.0461 & 0 & -1.1392 \\ 0.2109 & 0.2074 & 0.2022 & 0 \end{vmatrix}$$

$$\phi_{12} = \begin{vmatrix} 0 & -0.626 & 0.1685 & 0.1030 \\ 0.1081 & 0 & 0.2002 & 0.1493 \\ -0.9756 & -1.1592 & 0 & -0.7722 \\ -0.5962 & -0.8645 & 0.1333 & 0 \end{vmatrix}$$

$$\phi_{13} = \begin{vmatrix} 0 & 0.1053 & 0.1053 & -0.7827 \\ -0.6778 & 0 & 0 & -1.0353 \\ -0.6778 & 0 & 0 & -1.0353 \\ 0.1216 & 0.1608 & 0.1608 & 0 \end{vmatrix}$$

$$\phi_{14} = \begin{vmatrix} 0 & 0.1688 & 0.1813 & -0.3593 \\ -0.9160 & 0 & 0.0662 & -0.9839 \\ -0.9839 & -0.3593 & 0 & -1.0474 \\ 0.0662 & 0.1813 & 0.1930 & 0 \end{vmatrix}$$

$$\phi_{15} = \begin{vmatrix} 0 & 0.1685 & 0.1970 & 0.1345 \\ -1.0845 & 0 & 0.1021 & -0.6525 \\ -1.268 & -0.6571 & 0 & -0.9260 \\ -0.8662 & 0.1014 & 0.1438 & 0 \end{vmatrix}$$

$$\phi_{16} = \begin{vmatrix} 0 & 0.0248 & -1.7423 & -2.9451 \\ -0.8065 & 0 & -1.9199 & -3.0535 \\ 0.0535 & 0.0590 & 0 & -2.3744 \\ 0.0905 & 0.0938 & 0.0729 & 0 \end{vmatrix}$$

$$\phi_{17} = \begin{vmatrix} 0 & -0.4823 & -1.0249 & -0.2574 \\ 0.0749 & 0 & -0.9089 & 0.0641 \\ 0.1592 & 0.1412 & 0 & 0.1547 \\ 0.04 & -0.4124 & -0.9961 & 0 \end{vmatrix}$$

$$\phi_{18} = \begin{vmatrix} 0 & 0 & 0 & -1.2652 \\ 0 & 0 & 0 & -1.2652 \\ 0 & 0 & 0 & -1.2652 \\ 0.2331 & 0.2331 & 0.2331 & 0 \end{vmatrix}$$

$$\phi_{19} = \begin{vmatrix} 0 & 0.0696 & 0.1730 & 0.1364 \\ -0.3779 & 0 & 0.1583 & 0.1173 \\ -0.9385 & -0.8591 & 0 & -0.5772 \\ -0.7401 & -0.6365 & 0.1064 & 0 \end{vmatrix}$$

$$\phi_{20} = \begin{vmatrix} 0 & 0.0701 & 0.1312 & 0.1052 \\ -0.5003 & 0 & 0.1109 & 0.0784 \\ -0.936 & -0.7911 & 0 & -0.5594 \\ -0.7505 & -0.5594 & 0.0784 & 0 \end{vmatrix}$$

$$\phi_{21} = \begin{vmatrix} 0 & 0.1204 & 0.1353 & 0.1069 \\ -1.3493 & 0 & 0.0617 & -0.6191 \\ -1.5165 & -0.6922 & 0 & -0.9287 \\ -1.1989 & 0.0552 & 0.0828 & 0 \end{vmatrix}$$

$$\phi_{22} = \begin{vmatrix} 0 & 0.0380 & 0.0654 & 0.0792 \\ -0.7168 & 0 & 0.0534 & 0.0697 \\ -1.2342 & -1.0070 & 0 & 0.0448 \\ -1.4936 & -1.3137 & -0.8454 & 0 \end{vmatrix}$$

Results for $\boldsymbol{\theta} = 4$:

$$\phi_1 = \begin{vmatrix} 0 & -0.3657 & -0.4595 & -0.8410 \\ 0.0957 & 0 & -0.2788 & -0.7608 \\ 0.1202 & 0.0729 & 0 & -0.7102 \\ 0.2200 & 0.1991 & 0.1858 & 0 \end{vmatrix}$$

$$\phi_2 = \begin{vmatrix} 0 & 0 & -0.3024 & 0.1395 \\ 0 & 0 & -0.3024 & 0.1395 \\ 0.0670 & 0.0670 & 0 & 0.1548 \\ -0.6295 & -0.6295 & -0.6984 & 0 \end{vmatrix}$$

$$\phi_3 = \begin{vmatrix} 0 & -0.1376 & 0.0628 & 0.0492 \\ 0.0317 & 0 & 0.0683 & 0.0558 \\ -0.2726 & -0.2967 & 0 & -0.1713 \\ -0.2136 & -0.2423 & 0.0394 & 0 \end{vmatrix}$$

$$\phi_4 = \begin{vmatrix} 0 & -0.3736 & -0.2035 & -0.9919 \\ 0.0804 & 0 & 0.0675 & -0.9189 \\ 0.0438 & -0.3133 & 0 & -0.9708 \\ 0.2136 & 0.1978 & 0.2090 & 0 \end{vmatrix}$$

$$\phi_5 = \begin{vmatrix} 0 & 0.0363 & 0.0578 & 0.0227 \\ -1.4729 & 0 & 0.0449 & -1.1514 \\ -2.3417 & -1.8205 & 0 & -2.1541 \\ -0.9185 & 0.0284 & 0.0531 & 0 \end{vmatrix}$$

$$\phi_6 = \begin{vmatrix} 0 & 0.0688 & 0.0710 & -1.4479 \\ -0.7376 & 0 & 0.0176 & -1.6250 \\ -0.7612 & -0.1883 & 0 & -1.6358 \\ 0.1351 & 0.1516 & 0.1526 & 0 \end{vmatrix}$$

$$\phi_7 = \begin{vmatrix} 0 & 0.1495 & 0.1526 & 0.0367 \\ -1.6027 & 0 & 0.0304 & -1.5538 \\ -1.6354 & -0.3253 & 0 & -1.5875 \\ -0.3930 & 0.1450 & 0.1481 & 0 \end{vmatrix}$$

$$\phi_8 = \begin{vmatrix} 0 & 0.0651 & -0.7630 & -0.3914 \\ -0.3914 & 0 & -0.8575 & -0.5535 \\ 0.1269 & 0.1427 & 0 & 0.1090 \\ 0.0651 & 0.0921 & -0.6549 & 0 \end{vmatrix}$$

$$\phi_9 = \begin{vmatrix} 0 & 0.0916 & 0.0945 & 0.2341 \\ -0.3894 & 0 & 0.0230 & 0.2154 \\ -0.4014 & -0.0976 & 0 & 0.2142 \\ -0.9946 & -0.9153 & -0.9101 & 0 \end{vmatrix}$$

$$\phi_{10} = \begin{vmatrix} 0 & 0.1199 & -0.7383 & 0.0406 \\ -0.5568 & 0 & -0.9247 & -0.5238 \\ 0.1590 & 0.1991 & 0 & 0.1641 \\ -0.1887 & 0.1128 & -0.7621 & 0 \end{vmatrix}$$

$$\phi_{11} = \begin{vmatrix} 0 & -0.1606 & -0.2525 & -0.8909 \\ 0.0380 & 0 & -0.1949 & -0.8763 \\ 0.0598 & 0.0461 & 0 & -0.8544 \\ 0.2109 & 0.2074 & 0.2022 & 0 \end{vmatrix}$$

$$\phi_{12} = \begin{vmatrix} 0 & -0.4695 & 0.1685 & 0.1030 \\ 0.1081 & 0 & 0.2002 & 0.1493 \\ -0.7317 & -0.8694 & 0 & -0.5791 \\ -0.4472 & -0.6484 & 0.1333 & 0 \end{vmatrix}$$

$$\phi_{13} = \begin{vmatrix} 0 & 0.1053 & 0.1053 & -0.587 \\ -0.5083 & 0 & 0 & -0.7765 \\ -0.5083 & 0 & 0 & -0.7765 \\ 0.1216 & 0.1608 & 0.1608 & 0 \end{vmatrix}$$

$$\phi_{14} = \begin{vmatrix} 0 & 0.1688 & 0.1813 & -0.2695 \\ -0.687 & 0 & 0.0662 & -0.7379 \\ -0.7379 & -0.2695 & 0 & -0.7856 \\ 0.0662 & 0.1813 & 0.1930 & 0 \end{vmatrix}$$

$$\phi_{15} = \begin{vmatrix} 0 & 0.1685 & 0.1970 & 0.1345 \\ -0.8134 & 0 & 0.1021 & -0.4894 \\ -0.9510 & -0.4928 & 0 & -0.6945 \\ -0.6497 & 0.1014 & 0.1438 & 0 \end{vmatrix}$$

$$\phi_{16} = \begin{vmatrix} 0 & 0.0248 & -1.3067 & -2.2088 \\ -0.6049 & 0 & -1.4400 & -2.2901 \\ 0.0535 & 0.0590 & 0 & -1.7808 \\ 0.0905 & 0.0938 & 0.0729 & 0 \end{vmatrix}$$

$$\phi_{17} = \begin{vmatrix} 0 & -0.3617 & -0.7687 & -0.1930 \\ 0.0749 & 0 & -0.6817 & 0.0641 \\ 0.1592 & 0.1412 & 0 & 0.1547 \\ 0.0400 & -0.3093 & -0.7470 & 0 \end{vmatrix}$$

$$\phi_{18} = \begin{vmatrix} 0 & 0.0696 & 0.1730 & 0.1364 \\ -0.2834 & 0 & 0.1583 & 0.1173 \\ -0.7039 & -0.6443 & 0 & -0.4329 \\ -0.5551 & -0.4773 & 0.1064 & 0 \end{vmatrix}$$

$$\phi_{19} = \begin{vmatrix} 0 & 0 & 0 & -0.9489 \\ 0 & 0 & 0 & -0.9489 \\ 0 & 0 & 0 & -0.9489 \\ 0.2331 & 0.2331 & 0.2331 & 0 \end{vmatrix}$$

$$\phi_{20} = \begin{vmatrix} 0 & 0.0701 & 0.1312 & 0.1052 \\ -0.3752 & 0 & 0.1109 & 0.0784 \\ -0.7020 & -0.5933 & 0 & -0.4195 \\ -0.5629 & -0.4195 & 0.0784 & 0 \end{vmatrix}$$

$$\phi_{21} = \begin{vmatrix} 0 & 0.1204 & 0.1353 & 0.1069 \\ -1.0120 & 0 & 0.0617 & -0.4643 \\ -1.1374 & -0.5191 & 0 & -0.6965 \\ -0.8992 & 0.0552 & 0.0828 & 0 \end{vmatrix}$$

$$\phi_{22} = \begin{vmatrix} 0 & 0.0380 & 0.0654 & 0.0792 \\ -0.5376 & 0 & 0.0534 & 0.0697 \\ -0.9257 & -0.7552 & 0 & 0.0448 \\ -1.1202 & -0.9853 & -0.634 & 0 \end{vmatrix}$$

BIOGRAPHICAL SKETCH

The author was born in Bağcılar İstanbul in 1992. She completed her high school education in Cibali Lisesi and in 2010 she began industrial engineering education in İstanbul Şehir University with full scholarship program. The author graduated in 2015, in the same year she has started to study master of science in Galatasaray University.

PUBLICATIONS

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