An Extension of Smart Failure Modes and Effects Application for Wind Turbines

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ABSTRACT

Energy is a critical part of socio-economic growth and financial expansion. Wind energy, for instance, is a RE source that is native to the area and may assist in reducing reliance on fossil fuels. Electricity production from wind energy has increased dramatically in recent years all around the earth. The most critical challenge for the wind business is effectively predicting the dependability and availability of newly constructed WT. Furthermore, the FMEA approach has been utilized to investigate the dependability of a variety of power production systems. We suggest evaluating the windmill system technique using Smart FMEA, which is a mix of standard FMEA, DEA, and AHP. The components of WT are the focus of the failure mechanisms, impacts, and analyses. As components of WT, time and costs criticalities are gained. Several crucial choice criteria are validated under this study, in addition to weather (temperature, wind speed, wind direction, and so on) and wind turbine type. It also examines the interaction between components of wind farms that will be presented as downtime, cost criticalities are examined with a type of WT using AHP and DEA with crisp linguistic modeling and analyzes the impacts of decision factors while applying Smart FMEA on WT.

Keywords: Data Envelopment Analysis, Wind power, Wind turbine, Renewable Energy, Feasibility Study of Wind Farm, Smart FMEA, Analytical Hierarchy Process.

ÖZ

Enerji, sosyo-ekonomik büyümenin ve finansal genişlemenin kritik bir parçasıdır. Rüzgar enerjisi, bölgeye özgü bir yenilenebilir enerji kaynağıdır ve fosil yakıtlara olan bağımlılığın azaltılmasına yardımcı olabilir. Son yıllarda tüm dünyada rüzgar enerjisinden elektirik üretimi çarpıcı şekilde artmıştır. Rüzgar enerjisinde yeni inşa edilmiş rüzgar türbününün güvenilirliğini ve kullanılabilirliğini etkin bir şekilde tahmin etmek en kritik konudur. Çeşitli güç üretim sistemlerinin güvenilirliğini araştırmak için FMEA yaklaşımı kullanılmıştır. Bu çalışmada Standart FMEA, DEA ve AHP'nin bir karışımı olan Smart FMEA'yı kullanarak rüzgar türbünü system tekniğini değerlendirmenizi öneriyoruz. Rüzgar türbününün bileşenleri, arıza mekanizmalarının, etkilerinin ve analizlerinin odak noktasıdır. Bu çalışma kapsamında hava durumu (sıcaklık, rüzgarhızı, rüzgaryönü vb.) ve rüzgar turbine tipine ek olarak birkaç önemli seçim kriteri doğrulanmıştır. Ayrıca rüzgar çiftliklerinin bileşenleri arasındaki etkileşimi de incelenmiştir. Ayrıca, akıllı FMEA rüzgar santralleri üzerinde uygulanırken karar değişkenlerinin etkilerini analiz eder ve AHP, veri zarflama analizi kullanarak santrallerde oluşabilecek hatalardan kaynaklı duruş süresi ve maliyet kriterleri arasındaki ilişkileri inceler.

AnahtarKelimeler: Veri Zarflama Analizi, Rüzgar Enerjisi, Rüzgar Türbünü, Yenilenebilir Enerji, Rüzgar çiftliklerinde fizibilite çalışması, Akıllı Hata Türleri ve Etkileri Analizi, Analitik Hiyerarji Süreci

DEDICATION

To the soul of my father İlyas Selçuk KARA

To the source of my power, my mother Bilsel KARA

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First of all, I would like to thank Allah for making it possible for me to achieve this milestone. Also, I would like to express my deepest appreciation to my grandmother, Resmiye, my mother, Bilsel, my father, Selçuk, my aunt, Tanzer, my husband, Atilla, my sister, Sezin, and my brother Ogün for their support and encouragement. A special gratitude I give to my supervisor, Assoc. Prof. Dr. Sahand Daneshvar for his guidance throughout my studies. Special thanks go to Dr. Mustapha D. Ibrahim for his all support and co-operation. I have to appreciate the invaluable support given to me by Assoc. Prof. Dr. Gökhan İzbırak. Furthermore, I would also like to acknowledge with much appreciation the crucial role of my monitoring committee members, Prof. Dr. Bela Vizvari for his vital contributions. Special thanks go to the entire staff of the Department of Industrial Engineering. Finally yet importantly, I would like to appreciate the external jury members whose comments improved the thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABREVIATIONS

AD	Axiomatic Design
AHP	Analytic Hierarchy Process
AVG	Average
BBC	Banker, Charnes, & Cooper Model
BRIC	Brazil, Russia, India and China
CAPEX	Capital Expenditures
CF	Capacity Factor
CFD	Computational Fluid Dynamics
CI	Consistency Index
CO2	Carbon dioxide
CRS	Constant Return to Scale Model
D	Detection
DAIREC	Define, Analyze, Improve, Recommend, Evaluate and Control
DDF	Directional Distance Function
DEA	Data Envelopment Analysis
DFMEA	Design Failure Modes and Effects Analysis
DMUs	Decision-making units
DRS	Decreasing Returns to Scale
EC	Efficiency Change
EPDK	Energy Market Regulatory Authority
EPI	Environmental Performance Index
F	Failure
FC	Frontier Change

FFBD	Function Flow Boundary Diagram
FFMEA	Functional Failure Modes and Effects Analysis
FM	Failure Mode
FMEA	Failure Modes and Effects Analysis
FTA	Fault Tree Analysis method
GDP	Gross Domestic Product
GMI	Global Malmquist Indices
GMPI	Global Malmquist Productivity Index
HEP	Hydrological or Hydroelectric Power
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IRS	Increasing Returns to Scale
KBS	Knowledge- bed system
KDD	Knowledge Discovery and Data mining
LP	Linear Programming
MPI	Malmquist Productivity Index
O	Occurrence
OECD	Organization for Economic Cooperation and Development Countries
OHS	Occupational Health and Safety Specialist
OPEX	Operational Expenditure
P	Probability
PEC	Pure Efficiency Change
PFMEA	Process Failure Modes and Effects Analysis
PIM	Performance Improvement Management
PPE	Production Possibility Efficiency

PPS	Production Possibility Set
QFD	Quality Functional Deployment
RE	Renewable Energy
RES	Renewable Energy Sources
RI	Random Consistency Index
RP	Risk Priority
RPN	Risk priority number
S	Severity
SDG	Social Dimension Goals
SDGs	Sustainable Development Goals
SEC	Gross Scale Inefficiency
SEC	Scale Efficiency Change
SFMEA	Smart Failure Modes and Effects Analysis
SOD	Salient Object Detection
TC	Technical Change
TEC	Technical Efficiency Change
TFPC	Total Factor Productivity Change
VRS	Variable Return to Scale
WBG	World Bank
WE	Wind Energy
WEP	Wind energy potential
WF	Wind Farms
WP	Wind Power
WT	Wind Turbine
YCELP	Yale Center for Environmental Law and Policy

Chapter 1

INTRODUCTION

Energy is a critical part of socio-economic development and economic expansion. In modern cultures, energy resources are the essential markers of economic progress. Rapid population development and industrialization increased the need for energy, and the limited resources available are insufficient to supply this demand. The disparity between energy production and demand is steadily widening.

Economic existence depends on the availability of energy resources and the fulfillment of energy demands. Governments are concentrating their efforts on ensuring energy supply security, reducing foreign dependency on energy supplies, and cutting the price of energy derived from fossil fuels. Consequently, all governments in the world are interested in providing reliable, clean, and long-term energy. The finite sources of non-RE fossil fuels, as well as the wastes and pollutants they are behind in the world after usage, have heightened demand in RE in recent years.

1.1 Non-Renewable Energy Sources

Non-renewable sources of energy include petroleum, hydrocarbon gas liquids, natural gas, coal, and nuclear energy. Because its supply is limited to what humans can dig or remove from the ground, these sources of energy are referred to as non-renewable. These sources of energy are known as fossil fuels because coal, natural gas, and petroleum were produced during centuries from the burying remnants of ancient marine organisms that lived centuries ago.

1.1.1 Advantages and Disadvantages of NON-RES

Coal (fossil fuel) is made up of carbon and a variety of organic and inorganic chemicals. It is derived from fossilized plants. It's extracted from coal seams in the soil that are wedged between layers of rock. It is also burned to generate heat or power. Coal energy has the benefits of being a fully prepared fuel, being relatively inexpensive to mine and turn into energy, and having a longer supply life than oil or gas. One of the downsides of coal energy is that when it is burned, it emits pollutants into the atmosphere, including greenhouse gases.

Oil (fossil fuel) is a carbon-based fluid that is generated from fossilized organisms. Oil lakes are sandwiched between rock seams in the ground, and pipes are sunk down to the reserves to pump the oil out. The advantage of Oil is a ready-made fuel and relatively cheap to extract and convert into energy. The disadvantages of the oil are that when burned, it gives off atmospheric pollutants, including greenhouse gases, and only a limited supply.

Natural gases (fossil fuel) are methane and other gases stored in rock seams beneath the surface of the earth. Pipes are bored into the surface to extract the gases, which are then used to heat and cook homes. The advantages of Natural gas are a ready-made fuel, and it is a relatively cheap form of energy and a slightly cleaner fuel than coal and oil. The disadvantage of natural gas is that when burned, it gives off atmospheric pollutants, including greenhouse gases, and only a limited supply of gas.

Nuclear energy is created by mining radioactive elements like uranium and using the energy generated when the atoms of these elements are divided (by nuclear fission) in nuclear reactors to produce electricity. Nuclear energy has the following benefits: a tiny quantity of radioactive particles creates a lot more energy, natural resources are relatively inexpensive and may last for a long period, and it does not emit pollutants into the atmosphere. Nuclear reactors are costly to run, radioactive waste is very hazardous and must be securely kept for centuries or millennia (keeping is extremely costly), and nuclear material release can have catastrophic consequences for humans and the planet. In 1986, the worst nuclear plant catastrophe occurred in Chernobyl, Ukraine.

Biomass energy is produced from decomposing plant or animal waste, but it can also be a natural matter that is burned to produce energy, such as heat or electricity. An example of biomass energy is cottonseed rape (yellow flowers seen in the UK during the summer), which creates oil that can be used as a fuel for diesel engines after chemical modification. Biomass energy has the benefits of being a cheap and easily available form of energy, as well as being a long-term, sustainable source if crops are renewed. Biomass energy has the problem of emitting pollutants into the atmosphere, including greenhouse gas emissions when it is burnt. Biomass is a non-renewable source if plants are not replaced.

Falling trees provide wood energy, which is then burnt to provide warmth. Wood energy has the benefits of being a cheap and easily available form of energy, as well as being a long-term, sustainable source if trees are replenished. The downsides of wood energy include that when it is burned, it emits pollutants into the atmosphere, including greenhouse gas emissions, and it is a non-renewable source if plants are not replaced.

1.2 Renewable Energy Sources

RES that is derived from the soil and does not require any sort of manufacturing procedure. Because RES is not derived form of fossil fuels such as coal, oil, or carbon-based resources, CO2 emissions are kept to a minimum, and alternative energy, cause less environmental impact while generating energy from renewable sources. WE, solar energy, hydropower, biomass (plant matter) energy, geothermal energy (Earth's heat), and ocean energy (which includes wave, tidal, and sea current energy) are all examples of RE sources (Armstrong and Hamrin, 2000).

1.2.1 Advantages and disadvantages of RES

Cleaner air, fewer carbon emissions, natural resource conservation, and significant long-term savings are some of the most notable benefits of RES. Applying RE is the most effective strategy to minimize and eliminate carbon dioxide emissions.

The benefits of RE include a never-ending fuel source, zero-carbon pollution, cleaner air and water, a cheap type of power, and the creation of new employment. Increased capital expenses, unpredictable power output, power storage challenges, and factors of the environment are all negatives of RE.

Solar energy is gathered from the sun and is turned into power using solar panels. Solar energy has the benefit of possibly unlimited energy production and the ability for individual houses to have their own electrical source. The expense of manufacturing and installing solar panels is one of the downsides of solar energy.

WT (modern windmills) generate WE and convert it to electrical energy. The benefits of WE can be discovered individually, but they are commonly found in large groups in wind farms and a theoretically unlimited energy source. The manufacturing and installation of wind farms may be expensive, and several locals protest onshore wind farms, claiming that they pollute the environment.

With the movements of the wave’s powers generators, a tidal barrier (a type of dam) is erected around rivers to force water between gaps, and in the future, undersea windmills without barriers may be conceivable. The benefits of tidal energy are great for an island like the United Kingdom; it has the potential to create a great deal of energy, and the tidal barrier can serve as a bridge and assist avoid floods. The downsides of the WE include the high expense of building, the fact that only a few rivers are appropriate, the fact that it is criticized by certain environmental organizations as having a bad effect on wildlife, and the fact that it may restrict tidal movement and delay wastewater flowing over to shore.

The passage of saltwater in and out of a chamber on the beach compressed confined air and drives a generator, producing wave power. The benefits of wave power are appropriate for an island state, and tiny local activities are more frequent than large-scale enterprises. The downsides of wave energy include the high development cost and the possibility of opposition from municipal or conservation groups.

In volcanism, geothermal power may be utilized to harness the earth's inherent heat. Coldwater is pumped underground and emerges as steaming, that can be used for heating or to produce electricity that generates electricity. The benefit of that kind of power and it has the potential to provide a limitless source of power, and it has been effectively implemented in several nations, like New Zealand and Iceland. The disadvantages of this power include the cost of installation and the fact that it only performs in areas where there is volcanic activity. Additionally, geothermal, and volcanic activity may subside, rendering power plants obsolete, and risky components discovered underground must be greatly care disposed of.

HEP is a form of power derived from the flow of water in rivers, lakes, and dams. The benefit of this power is that it develops both water and energy storage. The HEP's downsides include its high cost of construction, the potential for flooding of nearby populations and landscapes, and dams' significant biological consequences on area hydrology.

Biomass energy is created when natural plant waste decomposes. It can also be a natural matter that is burned to produce energy, such as heat or electricity. For instance, biomass energy is cottonseed rape (the yellow flowers you see in the UK in the summer), which also generates oil which can be used as a fuel for diesel engines after chemical modification. Biomass energy has the benefits of being a cheap and easily available form of energy, as well as being a long-term, source of RE if plants are renewed. Biomass energy has the problem of emitting emissions into the environment; including greenhouse gas emissions when this is burnt. Biogas is a RE source if plants are replanted.

Falling trees provide wood energy, which is then burnt to provide heat and light. Wood energy has the benefits of being a cheap and easily available form of energy, as well as being a long-term, source of RE if trees are replenished. The downsides of wood energy include that it emits pollutants into the air, includes greenhouse gas emissions, and it is a natural resource if plants are replanted.

1.2.2 RES in OECD countries

The OECD is considered RE as a key driver of sustainable and socio-economic growth when they want to achieve sustainability. (Bergasse, E. et al., 2013) Selecting the best renewable energy options for the nation is also crucial since investments and capacity availability are both key factors. The demand for RE as a part of the nation's energy usage profile has been heightened by environmental changes in terms of fossil fuel use. (Abolhosseini, S. et al., 2014)

Because a nation's effectiveness in RE is not uniform, they should tailor their RE strategy to their capabilities in order to improve RE effectiveness. Researchers have identified RE as a means to achieving ecological responsibility and a continuous ecology. According to its economic, environmental, and social characteristics, nations should choose the highest productive and efficient RE choices. The most pressing issue is determining which option of RE is the most effective, productive, and beneficial to the nation. Organizations and the ministry are increasing their funding for renewable energy technologies in order to lower manufacturing costs.

1.2.3 RE in Turkey

Among the OECD nations, Turkey has the quickest power sector. Turkey has a strategic geographical position in the perspective of renewable energy resources, making RE a fantastic prospect for the country. Turkey has a large potential for REs which are known as RES such as solar, wind geothermal, hydro, wave, and biomass. The sun and wind were the initial sources of power, and we're turning to them again now, although in more technically advanced methods.

1.3 Wind Energy

WE is a RE source that is clean, dependable, low-cost to operate, and endless. WT generates power using a sustainable and environmentally benign resource: wind. Wind power is one of the most cost-effective RE technologies today, as it is a clean flue resource and a home source of power. WT converts WE into electricity without generating any waste. On existing farms or ranches, WT can be developed. Farmers and ranchers may keep working the land because the WT only uses a small portion of it. (Saidur et al., 2011) For the usage of the land, wind power facility investors pay a fee to the farmer or rancher. This has a significant economic impact on rural communities. (Saidur et al., 2011)

Compared to other sources of RE, WE is clean, ecologically beneficial, and less expensive. WT does not emit any pollutants into the atmosphere that contribute to acid rain or greenhouse emissions. When compared to petroleum-based power plants, the use of WE might also help to minimize water use. (Saidur et al., 2011) WE have the least impact on the environment when compared to other sources. With proper wind turbine design, wind turbine planning, and wind farm location selection, many negative consequences may be reduced.

1.3.1 Wind Power Energy in Turkey

WE have great potential in Turkey. However, the actual WE potential is insignificant. In Turkey, there are various areas with particularly high wind speeds. The northwestern, northern, and Aegean coastal regions of Turkey are all potential WE zone. Additional fields may be found in Turkey's Middle Black Sea and East Mediterranean areas. (Balat, 2005)

The analysis of long-term wind data captured and collected is used to determine the potential of wind’s location or a local region. Because of the high costs of wind assessments, they are required in places where major WT projects are being built. Because of the inexpensive cost of analysis, they are not required in tiny WT. (Balat, 2005). In this case, the WEP over various regions is given in Table 1, The WEP along with the western Aegean Sea coastal part of Turkey is given in Table 2, and wind characteristics for some selected cities in Turkey are given in Table 3.

Table 1: Turkey's WEP over different regions

Region	**Yearly Avg. Wind speed (m/s)**	**Yearly Avg. Wind density (W/m^2)**
South Anatolia	2,69	29,3
Mediterranean	2,45	21,4
Aegean	2,65	23,5
Central Anatolia	2,46	20,1
East Anatolia	2,12	13,2
The Marmara	3,29	51,9
Black Sea	2,38	21,3
Mean of Turkey	2,58	25,8

Sources: WERNC, 2000; Balat, 2004

Table 2: WEP along with western Aegean Sea coastal part of Turkey

Location	**Yearly Avg. Wind speed (m/s)**	**Yearly Avg. Wind density (W/m^2)**
Ayvalık	3,29	59,3
Bodrum	4,10	114,7
Bozcaada	6,36	319,5
Çanakkale	4,13	93,5
Dikili	2,5	20,5
Edremit	2,44	19,8
Gökçeada	4,14	112,9
İzmir	3,65	53,4
Mean of Turkey	**3,83**	**99,2**

Sources: Sen and Sahin, 1997

Table 3: The characteristics of some cities in Turkey

Station	Latitude N(degree)	Longitude E (degree)	Altitude (m)	Avg. Wind speed (m/s) at 5m	Avg. Wind speed (m/s) at 50 m
Adana	36,59	35,20	20	1,4	2,2
Afyon	38,45	30,32	1034	2,7	3,7
Akhisar	38,55	27,51	93	2,7	4,0
Alanya	36,33	32	7	1,9	2,6
Anamur	36,06	32,5	5	3,1	4,3
Ankara	39,57	32,53	894	1,8	2,6
Antalya	36,52	30,44	42	2,7	3,7
Balıkesir	39,38	27,53	147	2,8	4,2
Bandırma	40,21	27,58	58	5,8	6,9
Bodrum	37,02	27,26	27	3,7	5,1
Bozcaada	39,5	26,04	40	6,2	8,4
Bursa	40,13	29	100	2,2	3,0
Çanakkale	40,08	26,24	2	3,9	5,4
Çorlu	41,10	27,47	183	3,8	5,3
Gökçeada	40,12	25,54	72	3,5	5,5
İnebolu	41,59	33,46	64	3,7	5,2
Isparta	37,46	30,33	1004	2,5	3,6
Malatya	38,21	38,19	898	2,7	3,7
Mardin	37,18	40,44	1080	4,3	6,0
Muğla	37,13	28,22	646	2,6	3,7
Mersin	36,48	34,36	5	2,0	2,9
Samsun	41,21	36,15	44	2,7	3,6
Sarıyer	41,10	29,03	56	2,9	4,1
Sinop	42,02	35,10	32	3,6	5,1
Van	38,30	43,23	1671	2,1	2,9

Sources: *Oğulata, 2003*

1.4 Smart FMEA

FMEA is a method for systematically examining defects in a system. FMEA is a performance improvement approach that minimizes the occurrence of a failure or identifies and solves the problem kinds that occur in the systems and its function or subsystems as soon as feasible.

FMEA is an analytic approach, such as a combination of technology and human expertise to evaluate and prepare for such removal of predicted failure modes in a product or process (Besterfield, 2003).

FMEA is commonly used in three situations Functional, Design, and Process FMEA.

- Functional FMEA evaluates product and system faults that are related to their functional requirements.
- Design FMEA, examines failures linked with design aspects.
- Process FMEA, determines the likelihood of failure in processes of manufacturing and assembly.

FTA, AD, FFBD, AHP, QFD, KBS, KDD, DAIREC cycle methodologies could improve the practice of FMEA. In this thesis, we used Smart FMEA because we used to cost and time.

We recommend using Smart FMEA, which is a hybrid of traditional and smart FMEA. SFMEA examines the effects of decision variables on WT and examine the relationship between components of WT that will be given as downtime, cost criticalities are analyzing with type of WT and position using AHP and DEA with crisp linguistic modeling.

FMEA investigations are used to collect components and process data, and afterward-probable failures are discovered. At the same time, the reasons and repercussions of each failure, as well as the present control procedure, should be determined.

RPN is the multiplication of the occurrence (O), severity (S), and detection (D) of a failure, is used in traditional FMEA to establish the risk priority of failure modes. (Wang, Chin, Poon and Yang, 2009)

$$RPN = O\ X\ S\ X\ D \qquad (1)$$

FMEA employs a scale of one to ten to assess the likelihood of occurrence, the likelihood of non-detection, and the severity of an event. (Chang, Wei and Lee, 1999)

FMEA describes critical early corrective steps in a system, product, process, or service that will avoid defects and mistakes before happening and impacting the consumer. Therefore, for such a number of reasons, the crisp RPNs have been heavily criticized. (Wang, Chin, Poon and Yang, 2009)

Some of the more serious complaints include, but are not limited as follow:

- It is not taken into account the relative value of O, S, and D. The importance of the 3 risk variables is considered to be equal. When it comes to practical implementation of FMEA, it might not be the case.
- While various combinations of O, S, and D may generate the same RPN number, the risk consequences are likely to be significantly different. For instance, two events with the values of 6, 3, 5 and 5, 6, 3 for O, S, and D, respectively, have the same RPN value of 90. Therefore, the hidden risk consequences of the two occurrences will not be the same. It might result in wasted money and time, even, in rare situations, an unnoticed high-risk occurrence.
- The RPN level has several statistical parameters that are counterintuitive. It is generated just from three criteria, mostly in safety, because the traditional RPN technique does not account for indirect components relationships.

The variables of RPN are calculated with FMEA ratings for severity, detection, and Probability tables, where numbers one and ten represent the lowest and most significant risk factors, respectively. The RPN values range from 1 to 1000. The absolute best to absolute worst RPN value is ranges from 1 to 1000. A FM with such a greater RPN is more important and has a greater priority.

Using FMEA and FMEA procedures, a risk assessment is performed to enhance, eliminate, and identify "the hazards in wind energy facilities. The economic and financial, social and environmental, construction and management, political, and technological hazards associated with wind power facilities are all characterized. The RPN of energy plants is determined and a table is prepared using FMEA and FMEA methodologies for risks.

1.4.1 Failure modes of WE

Furthermore, the FMEA approach has been utilized to investigate the dependability of a variety of power production systems. FMEA is an inductive technique that may be used in all parts of failure analysis and is used to provide data for risk analysis. (Modarres, 1993)

SFMEA is a strategy for identifying and focusing on WT components. Other crucial choice factors are validated in this study, in addition to climate (temperature, wind speed, wind direction, and so on) and WT type.

It also examines the implications of choice factors while using Smart FMEA on WT. It investigates the interaction between WT components, which will be subjected to downtime, as well as cost criticalities associated with WT kind and placement, employing AHP and DEA with crisp modeling.

Failure modes of our study are listed in the below table.

Table 4: List of failures and cause of each failure's in our FMEA model.

FM	CAUSE OF FM	FM	CAUSE OF FM	FM	CAUSE OF FM	FM	CAUSE OF FM
FM1	Transportation problem	FM17	Wrong capacity calculation	FM33	Waste time	FM49	Electric Shock
FM2	Insufficient wind power (Powerless wind)	FM18	Wrong turbine design	FM34	Dangerous situation	FM50	Structure FMs.
FM3	Bird deaths	FM19	Wrong technology selection	FM35	Fall from high	FM51	Rotor blades FMs
FM4	Diminishing of cultivatable areas	FM20	Health problems	FM36	Difficulties of emergency evacuation	FM52	Mechanical Brake FMs.
FM5	Terrorism	FM21	Inefficiently working	FM37	Electrical Shock	FM53	Drive train FMs.
FM6	Civil unrest and war	FM22	Electrical FMs.	FM38	Fall of material during lifting	FM54	Generator FMs.
FM7	Disagreeable turbine selection	FM23	Strike of lightning	FM39	Moving materials crash	FM55	Gearbox FMs.
FM8	Suboptimal sitting of wind turbine into the wind farm	FM24	Injury of 3rd person	FM40	Manuel handling	FM56	Yaw system FMs.
FM9	Difficulties of emergency evacuation.	FM25	Devastate	FM41	Rollover of carrier vehicle	FM57	Sensor FMs.
FM10	Calculating mistake of investment costs	FM26	Broken of equipment	FM42	Rollover of shipment	FM58	Hydraulic system FMs.
FM11	Foreign exchange risk	FM27	Waste time	FM43	Driver borne problems	FM59	Electrical system FMs.
FM12	Credit risk	FM28	Environmental pollution	FM44	Operator borne problems	FM60	Control system FMs.
FM13	Inflation risk	FM29	Environmental pollution	FM45	Unexpected maintenance and repair	FM61	Hub FMs.
FM14	Electricity price risk	FM30	Health problems	FM46	Unexpected extension of periodic maintenance periods	FM62	Safety blade numbers.
FM15	Expensive spare parts	FM31	Health problems	FM47	Delay in procurement of equipment		
FM16	Change of law and regulations.	FM32	Health problems	FM48	Fire		

1.4.2 DEA in SFMEA Methods of WE

Organizations, educational institutes, energy and environment, internet companies, petroleum companies, renewable energies, natural gas, healthcare, batteries production, banking, sustainability, supply chains, road projects, level of life in some countries and regions, and other areas use the DEA technique.

DEA is a non-parametric approach for determining the effectiveness of a group of DMUs when they all use and generate the same inputs and outputs. When a DMU can create many outputs while using fewer inputs, it is effective. This cost-cutting approach turns the problem into an LP problem. Each FM of the Wind Farm will be treated as a DMU, for the above characteristics serving as inputs and outputs, according to the DEA concept. DEA models will then be used to assess the efficiency of these DMUs.

The DEA approach is used to determine which FM response is the most effective. To improve its dependability, the FMEA approach was updated and coupled with DEA. The effectiveness of the FMEA was calculated just on the basis of incidence, severity, and detection; in those other studies, cost and/or time were taken into account in various ways.

The FMEA methodology was merged with the DEA method in this study, and several of its applications, such as SOD efficiencies, exponential RPN, and multi-criteria decision-making theory, were investigated. To determine which FM's solution would be the most effective FM, the DEA approach is employed.

DEA model was developed by CCR. (Charnes, Cooper, & Rhodes, 1978) CCR is a metric that assesses the effectiveness of DMUs, which are homogenous units that operate under comparable conditions. The designation DMU general is appropriate due to the widespread use of DEA. It denotes any entity capable of converting inputs to outputs.

For the progress of DEA, a variety of models was presented. BCC changed (Banker, Charnes, & Cooper, 1984) the CRS model (Charnes et al., 1978) to add VRS in the production function, and introduced DDF (Chambers, Chung, & Färe, 1998; Färe & Grosskopf, 2000) to assess efficiency.

DEA creates a PPS by combining homogenous DMUs working under comparable conditions. The PPS is based on the premise that all conceivable input/output combinations exist. The PPS projects a boundary for the effective DMUs; DMUs on the boundary are effective DMUs, whereas ineffective DMUs are encircled by the boundary. The effective DMUs receive a rating of 1 (100%), whereas the ineffective DMUs receive a rating of less than 1 (100%).

In this work, we suggest evaluating wind turbine system techniques using Smart FMEA, which is a mix of standard FMEA, DEA, and AHP. The FMEA is focused on the WT components. WT acquires downtime and costs criticalities as components. Several crucial choice factors are validated in this study, in addition to climate (temp, wind speed, wind direction, and so on) and WT kinds. While using Smart FMEA on WT, it also analyzes the consequences of decision factors and investigates the interaction between WT components that will be subjected to downtime, as well as the price result of the experiences associated with WT kind and placement, employing AHP and DEA with precise linguistic modeling.

In this study, we suggest evaluating wind turbine system techniques using Smart FMEA, which is a mix of standard FMEA, DEA, and AHP. To solve DEA models, PIM (Performance Improvement Management) software is used as a one of well-known DEA software. The remaining of the thesis is arranged as follows to meet the study's objectives: Chapter 2 presents a literature review of studies that have proposed models with the aim of setting a target or efficiency improvement. Chapter 3 discusses the proposed data collection and methodology of Dual efficiency and productivity analysis of RE alternatives of OECD Countries and An Extension of SFMEA for WT. Chapter 4 then presents target setting models that accommodate predefined inputs/outputs of decision makers', supported with a numerical example and Dual efficiency and productivity analysis of RE alternatives of OECD Countries and An Extension of SFMEA for WT. Conclusions of the submitted paper and thesis with the future study are presented in Chapter 5.

Chapter 2

LITERATURE REVIEW

In this chapter literature review is divided into the topics RE, WT, and WE, FMEA Method, DEA Method, and AHP Method.

2.1 Literature Review of RE

This section of our research provides a brief overview of several sources of energy. The usage of renewable energy resources is steadily expanding, as is the demand for it, as opposed to traditional sources of energy in every corner of the globe. The usage of these resources can meet the increased energy demand, and studies into this are underway.

That work gives a basic understanding of various sources of energy. As a result, there is a pressing need to investigate these resources more thoroughly in order to optimize their use in a variety of applications throughout the globe.

Short research is conducted to gain an understanding of how these RE sources were utilized in the past and to gain an understanding of their development. As a result of this assessment, some of the most valuable research is summarized in Table 5, which is mentioned below.

Table 5: A literature review of RE

	Year of Publication	Topic	Author (s)	Summary
1	1964	Technology and scale in electricity generation. Econometrica: Journal of the Econometric Society,	Dhrymes, P.J. and M. Kurz	The productive process of electricity generation is examined, and a modified substitution model is employed, permitting differentiation between returns to scale to labor and to other factors.
2	1983	A long-term global energy-economic model of carbon dioxide release from fossil fuel use. Energy Economics, 1983	Edmonds, J. and J. Reilly	Edmonds and Reilly worked on the Energy Economics, and they have an economic model of carbon dioxide release from fossil fuel use that is given the details at A long-term global energy-economic model of CO2 release from fossil fuel use, book in 1983.
3	1994	It's not easy being green. Reader in Business and the Environment, 1994.	Walley, N. and B. Whitehead,	They used such data as environmental rating, credit rating, and accumulated earnings ratio of companies listed in the manufacturing sector on the first section of the Tokyo Stock Exchange. To investigate the relationship between environmental management and economic performance. They performed a path with using structural equation modeling for a terminal economic performance path and a terminal environmental management path.
4	1995	A manual for the economic evaluation of energy efficiency and renewable energy technologies. 1995, National RE Lab., Golden, CO (1995)	Short, W., D.J. Packey, and T. Holt	A manual for the economic evaluation of energy efficiency and RE technologies provides guidance an economic evaluation approached, metrics and level of detail required while offering a consistent basis on which analysts can perfom analyses using standard assumptions and bases.
5	2000	The Renewable Energy Policy Manual. Washington, USA: United States Export Council for Renewable Energy. (2000)	Armstrong, A.J., Hamrin, J	An undertaking that attempts to provide renewable energy policy guidance to policy strategists who operate across a spectrum of national energy systems inherently contains both the flaws and the strengths of "universal" or general concepts.
6	2001	Gaining from green management: environmental management systems inside and outside the factory. California management review, 2001	Florida, R. and D. Davison,	Environmental Management Systems (EMSs) provide firms with additional sources of information and leverage over their environmental and business processes and performance. It is relatively new and rather innovative management practices that The results of a survey of manufacturing plants that have adopted EMSs are reported at this article.
7	2003	Economic potential of biomass based fuels for greenhouse gas emission mitigation. Environmental and resource economics, 2003	Schneider, U.A. and B.A. McCarl	In this paper, production and biofuel processing for the designated energy crops switch grass, hybrid poplar, and willow in an U.S. Agricultural Sector Model along with data on traditional crop-livestock production and processing, and afforestation of cropland data is incorporated. And Economic potential of biomass based fuels for greenhouse gas emission mitigation is studied.
8	2004	To Use of Renewable Energy Sources for Energy in Turkey and Potential Trends". Energy Exploration and Exploitation, Vol. 22 (2004)	Balat, M	In this paper, use of renewable sources in Turkey is investigated and potential trends are presented. In this paper, The market for renewable energy and Energy efficiency in Turkey is specified as substantial.
9	2005	Biomass energy used in a sawmill. Applied energy, 2005	Dowaki, K. and S. Mori	A comparison of a gasification-cogeneration system is analyzed the environmental improvement and the economics of a biomass-energy system in a sawmill with a direct-combustion system using scrap-wood material as feedstock fuel. And the break-even point for marketability of the business taking the surplus electric-power into consideration is estimated under the assumption of a renewable-energy purchase system in Japan.
10	2006	Yenilenebilir energy kaynaklari ve yenilenebilir energy piyasalari. Energy Piyasasi Duzenleme Kurulu (EPDK), Expertise Thesis, Ankara, Turkey. (2006)	Unal, E.	The Expertise thesis of Renewable energy sources and renewable energy markets. Energy Market Regulatory Board (EMRA) is written by Unal in 2006.

Table 5: Cont.

	Year of Publication	Topic	Author (s)	Summary
11	2007	Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. Energy Policy, 2007	Chien, T. and J.-L. Hu	The effects of renewable energy on the technical efficiency of 45 economies during the 2001–2002 period through (DEA) is analyzed this paper. In this paper, labor, capital stock, and energy consumption are taken as inputs and real GDP is taken as output. They analyzed the relation between RE and inputs with efficiencies and Compared to non-OECD (Organization for Economic Co-Operation and Development) economies, OECD economies' technical efficiency with geothermal, solar, tide, and wind fuels in renewable energy.
12	2009	Global potential of sustainable biomass for energy. 2009	Ladanai, S. and J. Vinterbäck	In this report, the global potential of sustainable biomass for energy is analyzed and compared with other resources.
13	2011	Environmental impact of wind energy. Renewable and Sustainable Energy Review (2011)	Saidur, R., Rahim, N., Islam, M., &Solangi, K.	The latest literatures in terms of thesis (MS and PhD), journal articles, conference proceedings, reports, books, and web materials about the environmental impacts of wind energy compiled in this paper and also the comparative study of wind energy, problems, solutions and suggestion as a result of the implementation of wind turbine is given in this paper.
14	2011	Measuring energy efficiency: Indicators and potentials in buildings, communities and energy systems. 2011	Forsström, J.	Forsström is studied about the energy efficiency measuring by using indicators and potentials in buildings, communities and energy system in this paper.
15	2013	Scientific production of renewable energies worldwide: An overview. Renewable and Sustainable Energy Reviews (2013)	Manzano-Agugliaro	The scientific production of renewable energies, namely, solar, wind, biomass, hydropower and geothermal, from 1979 to 2009 is reviewed in this paper. Also The production of all the countries in the world is analyzed, paying particular attention to renewable energies and research institutions. The production of scientific research for each type of energy is represented on world maps to show the degree of relationship between this research and the resources of these energies.
16	2013	The relationship between energy and socio-economic development in the Southern and Eastern Mediterranean. CASE Network Reports, 2013	Bergasse, E	In this paper the relationship between energy and socio-economic development in the Southern and Eastern Mediterranean is done by Bergasse.
17	2013	Dumlu pınar Üniversitesi Sosyal Bilimler Dergisi EYİ 2013 Özel Sayısı, The analysis of the risk of renewable energy resources by using fuzzy FMEA technique	Yük. Lis. Öğr. HülyaYÖRÜKOĞLU, Yrd. Doç. Dr.Celal ÖZKALE, Yrd. Doç. Dr. Burcu ÖZCAN, Yrd. Doç. Dr.Cenk ÇELİK.	In this research the risk analysis of renewable energy resources are done by using fuzzy failure modes and effects technique.
18	2013	World Energy Outlook 2013	IEA	Word energy Outlook is written in 2013 by IEA.
19	2014	Environmental efficiency of investments in renewable energy: Comparative analysis at macroeconomic level. Renewable and Sustainable Energy Reviews, 2014	Cicea, C	In this paper, Environmental efficiency of investments in renewable energy is studied and a Comparative analysis at macroeconomic level is done.
20	2014	A review of renewable energy supply and energy efficiency technologies. 2014	Abolhosseini, S., A. Heshmati, and J. Altmann	This paper presented a review of renewable energy supply and energy efficiency technologies.

Table 5: Cont.

	Year of Publication	Topic	Author (s)	Summary
21	2015	The static and dynamic environmental efficiency of renewable energy: A Malmquist index analysis of OECD countries. Renewable and Sustainable Energy Reviews, 2015	Woo, C	In this research a malmquist index analysis of OECD countires is presented. And the static and dynamic environmental efficiency of renewable energy is studied in this table.
22	2015	Feasibility of using more geothermal energy to generate electricity. Journal of energy resources technology, 2015.	Wong, K.V. and N. Tan	Feasibility of using more geothermal energy to generate electricity is done by Wong and et al in this paper.
23	2018	Solar energy: Potential and future prospects. Renewable and Sustainable Energy Reviews, 2018	Kabir, E	In this article, the merits and demerits of solar energy technologies are both discussed.
24	2018	Significance and challenges of biomass as a suitable feedstock for bioenergy and biochemical production: A review. Energies, 2018	Ahorsu, R., F. Medina, and M. Constantí,	In this paper a review is studied about the Significance and challenges of biomass as a suitable feedstock for bioenergy and biochemical production.
25	2019	RE consumption in Coastline Mediterranean Countries: impact of environmental degradation and housing policy. Environmental Science and Pollution Research, 2019	Alola, A.A., U.V. Alola, and S. Saint Akadiri	In this paper, the impact of environmental degradation and housing policy is studied about the Renewable energy consumption in Coastline Mediterranean Countries
26	2019	Renewable energy consumption in EU-28 countries: policy toward pollution mitigation and economic sustainability. Energy Policy, 2019	Saint Akadiri, S	The existence of positive and significant long-run nexus among environmental sustainability, renewable energy consumption and economic growth in the EU-28 countries is confirmed in this study.
27	2020	Assessment of the role of renewable energy consumption and trade policy on environmental degradation using innovation accounting: Evidence from the US. Renewable Energy, 2020	Usman, O., A.A. Alola, and S.A. Sarkodie	The dynamic effect of renewable energy consumption, economic growth, bio capacity and trade policy on environmental degradation in the United States from 1985Q1 to 2014Q4 is investigated this study. This objective is achieved and an autoregressive distributed lag (ARDL) model to obtain the long-run and short-run dynamic coefficients is applied in this study.
28	2020	Energy efficiency evaluation based on data envelopment analysis: a literature review. Energies, 2020	Xu, T	A literature review is presented in this paper about Energy efficiency evaluation based on data envelopment analysis.
29	2020	Policy-making for renewable energy sources in search of sustainable development: a hybrid DEA-FBWM approach. Environment Systems and Decisions, 2020	Kolagar, M	A hybrid approach by combining data envelopment analysis (DEA) and fuzzy best–worst method (FBWM) for the prioritization of renewable energy sources (RESs) in Iran is proposed in this study and consideration of the technical, economic, environmental, social, and political sustainability dimensions is presented to indicate the most efficient RESs in Iran.
30	2020	Integrated analysis of energy-economic development-environmental sustainability nexus: Case study of MENA countries. Science of The Total Environment, 2020.	Ibrahim, M.D. and A.A. Alola	An Integrated analysis of energy-economic development-environmental sustainability nexus is studied in this paper and also Case study of MENA countries is studied in this paper.

Table 5: Cont.

	Year of Publication	Topic	Author (s)	Summary
31	2021	Hydropower, in Distributed Renewable Energies for Off-Grid Communities (2021)	Mohamed, T	Mohammed is studied about the Hydropower, in Distributed Renewable Energies for Off-Grid Communities in 2021
32	2021	An overview of nitrogen oxides emissions from biomass combustion for domestic heat production. Renewable and Sustainable Energy Reviews, 2021	Ozgen, S., S. Cernuschi, and S. Caserini	Ozgen and et al is studied about renewable and sustainable energy. An overview of nitrogen oxides emissions from biomass combustion for domestic heat production is done by them.
33	2021	Renewable energy explained. 2021	EIA	The renewable Energy is explained in this research as detail.
34	2021	Attitude toward and Awareness of Renewable Energy Sources: Hungarian Experience and Special Features. Energies, 2021	Szakály, Z	The awareness of renewable energy sources (RES), the relationship between self-reported and actual knowledge, and the correlation among the knowledge of renewable energy sources, the characteristic stereotypes, and the typical attitude of different social groups to energy, is analysed in this paper and comparing them with international experience.
35	2021	Energy Utilization Efficiency of China Considering Carbon Emissions—Based on Provincial Panel Data. Sustainability, 2021	Huang, G	A data envelopment analysis (DEA) model to calculate the energy utilization efficiency of China's provinces and regions from the perspective of environmental constraints, including four inputs—labor force, capital stock, energy consumption and carbon emission—and one output, GDP is studied in this paper.
36	2021	Attitude toward and Awareness of Renewable Energy Sources: Hungarian Experience and Special Features. Energies, 2021	Szakály, Z	The awareness of renewable energy sources (RES), the relationship between self-reported and actual knowledge, and the correlation among the knowledge of renewable energy sources, the characteristic stereotypes, and the typical attitude of different social groups to energy, is analysed in this paper and comparing them with international experience.
37	2021	Energy Utilization Efficiency of China Considering Carbon Emissions—Based on Provincial Panel Data. Sustainability, 2021	Huang, G	A data envelopment analysis (DEA) model to calculate the energy utilization efficiency of China's provinces and regions from the perspective of environmental constraints, including four inputs—labor force, capital stock, energy consumption and carbon emission—and one output, GDP is studied in this paper.
38	2021	Access to clean fuels and technologies for cooking. Sustainable Energy for All (SE4ALL) database from WHO Global Household Energy database. 2021	WBG	In this WBG, the access for cooking to clean fuels and technologies are presented in detail.

2.2 Literature Review of WT and WE

This section of our thesis provides a brief overview of several WT and WE resources. WE have shown to be one of the greatest promising alternative energies. Many WT or WE studies have been published in the literature in recent years. At this part of the review some of the important surveys about WT.

Short research is conducted to gain an understanding of how these WT and WE sources were utilized in the past and to gain an understanding of their development. As a result of this assessment, some of the most valuable research is summarized in Table 6, which is mentioned below.

Table 6: A literature review of WT and WE

	Year of Publication	Topic	Author (s)	Summary
1	1997	Regional assessment of wind power in western Turkey by the cumulative semi variogram method". Renewable Energy, Vol. 12 (1997)	Sen, Z. and A. D. Sahin	Regional patterns of wind energy potential along the western Aegean Sea coastal part of Turkey are evaluated by considering its regional variability using cumulative semi variogram models. The CSV techniques yielded the radius of influence for wind velocity and Weibull distribution parameters. Dimensionless SRD functions are obtained from the sample CSV. These SRD functions help to make simple regional predictions for the wind energy or wind velocity distribution parameters. The methodology has been applied for predicting the wind velocity in Turkey along the Aegean Sea coast.
2	2003	Energy sector and wind energy potential in Turkey. Renewable and Sustainable Energy Reviews, Vol. 7 (2003)	Oğulata, R.T	Oğulata presented the prevailing and the expected energy situation and energy demand and discussed the Wind energy potential in Turkey in this paper.
3	2005	Wind Energy Potential in Turkey, ENERGY EXPLORATION & EXPLOITATION (2005)	Balat, Havva	In this research the wind energy potential is analyzed for Turkey. The Energy exploration and exploitation is studied in this research by Balat.
4	2006	Global Wind Energy Council (GWEC), Sept. 2006.	Global Wind Energy Outlook	The Global Wind Energy Council is studied about Global Wind Energy in 2006.
5	2007	A review of wind energy technologies. Renewable and Sustainable Energy Reviews (2007)	Herbert, G. J., Iniyan, S., Sreevalsan, E., &Rajapandian, S	Herbert et al. is studied the review of wind energy technologies and also reviewed the renewable and sustainable Energy in 2007.
6	2007	Thesiss-EMO Project Event, Estimated balanced of Turkey's electrical energy, Wind farm's set up cost of and solving the production parameters's analyze at Matlab&Simulink software, YTU, Electric electirical faculty, Electric Engineering Department. (2007)	Murat Ağçay and Assist. Prof. Dr. Ferit Attar	The thesis research of Mr. Ağçay was about estimation of the Turkey's electrical energy, set up cost of wind farm. In this thesis the production parameters' are analyzed at Matlab & Simulink software.
7	2013	Wind farm layout optimization under uncertainty with landowners' financial and noise concerns. Iowa State University (2013)	Chen, L	In this research, the wind farm layout optimization is analyzed under certainty with landowners' financial and noise concerns.
8	2016	Evaluation of wind turbine noise by soft computing methodologies: A comparative study. Renewable and Sustainable Energy Reviews (2016)	Anicic, O., Petković, D., &Cvetkovic, S	Anicic et al. is studied a comparative study for renewable and sustainable energy about the soft computing methodologies to evaluate wind turbine noise.
9	2018	Exploration of wind energy in India: A short review. in 2018 National Power Engineering Conference (NPEC). 2018.	Sitharthan, R., J. Swaminathan, and T. Parthasarathy	The India Wind energy is discovered in National Power Engineering Conference in 2018.
10	2019	Overview of ocean power technology. Energy, 2019	Wilberforce, T	In this research, the Ocean power technology is overviewed in 2019 by Wilberforce.

Table 6: Cont.

	Year of Publication	Topic	Author (s)	Summary
11	2009	The dual sustainability of wind energy. Renewable and Sustainable Energy Reviews, 2009	Welch, J.B. and A. Venkateswaran	An analysis of the financial economics of wind energy and endeavor to determine whether it is sustainable without the extensive government support that has helped to create and nurture this growth industry is analyzed in this article with using reliable, proprietary data from field research.

2.3 Literature Review of FMEA Method

This section of our thesis provides a brief overview of the FMEA Methodology. Many FMEA studies have been published in the literature in recent years. At this part of review, some of the important surveys about FMEA are presented in Table 7, which is mentioned below.

Short research is conducted to gain an understanding of how these FMEA sources were utilized in the past and to gain an understanding of their development. As a result of this assessment, some of the most valuable research is summarized in Table 57, which is mentioned below.

Table 7: A literature review of FMEA method

	Year of Publication	Topic	Author (s)	Summary
1	1999	Failure mode and effects analysis using fuzzy method and grey theory. Kybernetes. (1999)	Chang, C. L., Wei, C. C., Lee, Y. H.	Fuzzy theory to eliminate the conversion debate by directly evaluating the linguistic assessment of factors, and uses grey theory to obtain risk priority number by assigning relative weighting coefficient without any utility function is applied in this study.
2	2001	Modified FMEA for fishing vessels: A fuzzy set and grey theory approach. International Offshore and Polar Engineering Conference Stavanger, Norway. (2001)	Pillay, A., Wang, J., Jung G. M., Kwon,YS., Loughran, C. G., l'Anson, T., Wall, A. D., Ruxton, T	Pillay et al. is studied about A fuzzy set and grey theory approach for International Offshore and Polar Engineering Conference. In this paper they modified FMEA for fishinf vessels.
3	2011	Risk analysis method: FMEA/FMECA in the organizations. IJBAS-IJENS, (2011)	Lipol, L. S., Haq, J	The risk analysis methods are presented in this research. The FMEA/ FMECA methods are presented in this paper.
4	2011	Failure mode and effects analysis using fuzzy evidential reasoning approach and grey theory. Expert Syst. Appl. 2011	Liu, H.-C.; Liu, L.; Bian, Q.-H.; Lin, Q.-L.; Dong, N.; Xu, P.-C	Liu and et al is studied about Failure mode and effects analysis. Fuzzy evidential reasoning approach and grey theory is used in this paper.

Table 7: Cont.

	Year of Publication	Topic	Author (s)	Summary
5	2013	Fuzzy Extent Analysis for Food Risk Assessment, in: Fuzzy Hierarchical Model Risk Assess., Springer London, London, 2013	H.K. Chan, X. Wang	In this research Fuzzy extent analysis is studied for Food risk assessment in Fuzzy Hierarchical Model Risk Assess.
6	2013	A Fuzzy-FMEA Risk Assessment Approach for Offshore Wind Turbines. Int. J. Prognostics Health Manag (2013)	Dinmohammadi, F., Shafiee, M.	In this paper, the risk assessment approach of Fuzzy-FMEA is studied for Offshore Wind Turbines.
7	2015	A fuzzy Bayesian belief network for safety assessment of oil and gas pipelines, Struct. Infrastruct. Eng. 2479 (2015)	G. Kabir, R. Sadiq, S. Tesfamariam,	A safety assessment model for O&G pipeline failure by incorporating fuzzy logic into Bayesian belief network is developed and also fuzzy Bayesian belief network (FBBN) model explicitly represents dependencies of events, updating probabilities and representation of uncertain knowledge is proposed in this study.
8	2017	An extension to Fuzzy Developed Failure Mode and Effects Analysis (FDFMEA) application for aircraft landing system, Saf. Sci. 98 (2017)	M. Yazdi, S. Daneshvar, H. Setareh	Yazdi and at al. is studied Fuzzy FMEA. They developed FDFMEA model for aircraft landing system.
9	2017	FMEA in Total Quality Management, 2017	D.R. Kiran	Total quality management and the failure modes and effects analysis of TCM is studied in this research.
10	2017	An extension of Fuzzy Improved Risk Graph and FAHP for determination of chemical complex Safety Integrity Levels, Int. J. Occup. Saf. Ergon. 25 (2017)	M. Yazdi,	Yazdi is studied about the determination of chemical complex Safety Integrity levels. He improved Risk Graph and Fuzzy Analytical Hierarchy process as an extension of Fuzzy model.
11	2017	A fuzzy Bayesian network approach for risk analysis in process industries, Process Saf. Environ. Prot. (2017)	M. Yazdi, S. Kabir	In this paper, Yazdi and Kabir are studied about Risk analysis in process industries. They approached a fuzzy Bayesian network for risk analysis in process industries.
12	2017	A comprehensive review of effect of biodiesel additives on properties, performance, and emission. in IOP Conference Series: Materials Science and Engineering, 2017	Madiwale, S., A. Karthikeyan, and V. Bhojwani.	The effect of biodiesel additives on properties, performance, and emission is reviewed comprehensively in this paper.
13	2018	Risk assessment based on novel intuitionistic fuzzy-hybrid-modified TOPSIS approach. (2018)	M. Yazdi	TOPSIS approach is studied in this paper by Yazdi. He studied the intuitionistic fuzzy hybrid TOPSIS approach is proposed to deal with limitations of a crisp risk matrix and uncertainties of group decision makers using experts' opinions in linguistic terms.
14	2020	Exploring environmental efficiency of the European agricultural sector in the use of mineral fertilizers. Journal of Cleaner	Expósito, A. and F. Velasco	The environmental efficiency of the agricultural sector regarding the use of mineral fertilizers in the period 2001–2012 for a group of European countries is analyzed in this paper.

2.4 Literature Review of DEA Method

This section of our thesis provides a brief of DEA Method. Many DEA studies have been reported in the literature in recent years. At this part of review some of the important surveys about DEA are presented in Table 8, which is mentioned below.

Short research is conducted to gain an understanding of how these DEA sources were utilized in the past and to gain an understanding of their development. As a result of this assessment, some of the most valuable research is summarized in Table 8, which is mentioned below.

Table 8: A literature review of DEA method

	Year of Publication	Topic	Author (s)	Summary
1	1982	The economic theory of index numbers and the measurement of input, output, and productivity. Econometrica: Journal of the Econometric Society, 1982	Caves, D.W., L.R. Christensen, and W.E. Diewert	Index number procedures for making comparisons under very general circumstances developed in this paper. Malmquist input, output, and productivity comparisons are defined for structures of production with arbitrary returns to scale, substitution possibilities and biases in productivity change.
2	1984	Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management science, 1984	Banker, R.D., A. Charnes, and W.W. Cooper	In this paper, Banker and et al. is studied about estimation technical and scale inefficiencies in Data envelopment analysis. They worked on some models for relevant estimations.
3	1986	Efficiency analysis for exogenously fixed inputs and outputs. Operations research, 1986	Banker, R.D. and R.C. Morey	In this paper, an efficiency analysis is done for exogenously fixed inputs and outputs.
4	1988	An interactive MOLP procedure for the extension of DEA to effectiveness analysis. Journal of the operational research society (1988)	Golany, B	A new, interactive multi-objective linear-programming procedure to aid decision-makers in setting up goals for desired output is presented in this paper. And generated the procedure relies on empirical production functions by the use of data envelopment analysis.
5	1990	The Analytic Hierarchy process." Mc graq-Hill, New York. (1990)	Saaty, T.L.	The Analytic Hierarchy process is studied in this research by Saaty.
6	1992	Estimation of returns to scale using data envelopment analysis. European Journal of operational research, 1992	Banker, R.D. and R.M. Thrall	In this paper, data envelopment analysis is used to estimate returns to scale.
7	1993	A procedure for ranking efficient units in data envelopment analysis. (1993)	Andersen, P., & Petersen, N. C	A ranking efficient unit in data envelopment analysis procedure is studied in this paper.
8	1993	What every Engineer should know about Reliability and Risk Analysis. (1993)	Modarres, M.	The Reliability and Risk analysis for Engineering knowledge is presented in this research by Modarres.
9	1994	Production frontiers. 1994: Cambridge university press.	Rolf Färe, Rolf Fèare, Shawna Grosskopf, C. A. Knox Lovell	In this book, Färe et al. is discussed the production frontiers.

Table 8: Cont.

	Year of Publication	Topic	Author (s)	Summary
10	1997	Weights restrictions and value judgements in data envelopment analysis: evolution, development and future directions. (1997)	Allen, R., Athanassopoulos, A., Dyson, R. G., &Thanassoulis, E.	A review of the evolution, development and future research directions on the use of weights restrictions and value judgments in DEA is provided and The incorporation of value judgments in DEA was motivated by applications of the method in real life organizations are argued in this paper.
11	1998	Profit, directional distance functions, and Nerlovian efficiency. Journal of optimization theory and applications, 1998	Chambers, R. G., Chung, Y., &Färe, R	In this paper, The directional technology distance function is introduced, an interpretation as a min-max, and compared with other functional representations of the technology including the Shephard input and output distance functions and the McFadden gauge function is given.
12	2000	Environmental efficiency in carbon dioxide emissions in the OECD: A non-parametric approach. Journal of Environmental Management, 2000.	Zaim, O. and F. Taskin,	In this paper, based on the assumption that there is just one production process behind the production of both goods and pollution emissions are adopted.
13	2001	Environmental efficiency and regulatory standards: the case of CO2 emissions from OECD industries. Resource and Energy Economics, 2001.	Zofío, J.L. and A.M. Prieto	In this paper, Zofio and et al. is studied the Environmental efficiency and regulatory standards and A case of CO2 emissions from OECD industries is studied.
14	2003	Total Quality Management (pp. 377–405). New Jersey: Pearson Education, Inc. (2003)	Besterfield, D., Besterfield-M., C., Besterfield, G.H., Besterfield-S., M.	Besterfield and et al. is studied about the total quality management.
15	2004	DEA Malmquist productivity measure: New insights with an application to computer industry. European journal of operational research, 2004	Chen, Y. and A.I. Ali	In this study, an extension to the DEA-based Malmquist approach by further analyzing these two Malmquist components are provided.
16	2005	A global Malmquist productivity index. Economics Letters, 2005	Pastor, J.T. and C.K. Lovell	A global Malmquist productivity index that is circular, and that gives a single measure of productivity change is provided in this study.
17	2006	Introduction to data envelopment analysis and its uses: with DEA-solver software and references. 2006: Springer Science & Business Media.	Cooper, W.W., L.M. Seiford, and K. Tone	In this book, Introduction to data envelopment analysis and its uses are discussed with DEA-solver software and references.
18	2008	Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA. Socio-economic planning sciences, 2008	Emrouznejad, A., B.R. Parker, and G. Tavares	In this paper, Efficiency and productivity is evaluated and A survey presented and the first 30 years of scholarly literature in DEA is analyzed.
19	2009	DEA models for ratio data: Convexity consideration. Applied Mathematical Modelling (2009)	Emrouznejad, A., & Amin, G. R.	Some difficulties of using standard DEA models in the presence of input and/or output-ratios is shown in this paper and also defined a new convexity assumption when data includes a ratio variable.

Table 8: Cont.

	Year of Publication	Topic	Author (s)	Summary
20	2009	The hyperbolic-oriented efficiency measure as a remedy to infeasibility of super efficiency models. Journal of the operational research society. (2009)	Johnson, A. L., & McGinnis, L. F	In this paper, an alternative to the input-oriented, output-oriented, and directional efficiency measures in super efficiency models are provided with the hyperbolic-oriented efficiency and the distinct advantage of eliminating the infeasibility problem for positive input/output data is presented.
21	2009	Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean. Expert Systems with Applications. (2009)	Wang, Y. M., Chin, K. S., Poon, G. K. K., Yang, J. B.	The risk factors O, S and D as fuzzy variables and evaluate them using fuzzy linguistic terms and fuzzy ratings are treated in this paper. And proposed fuzzy risk priority numbers (FRPNs) for prioritization of failure modes.
22	2010	A semi-oriented radial measure for measuring the efficiency of decision making units with negative data, using DEA. European Journal of operational research (2010)	Emrouznejad, A., Anouze, A. L., &Thanassoulis, E	In this paper, DEA is used for measuring the efficiency of decision making units with negative data with A semi-oriented radial.
23	2010	Differential characteristics of efficient frontiers in data envelopment analysis. (2010)	Podinovski, V. V., &Førsund, F. R	Podinovski and Forsund studied the differential characteristics of efficient frontiers in data envelopment analysis.
24	2010	An alternative measure of the ICT-Opportunity Index. (2010)	Emrouznejad, A., Cabanda, E., &Gholami, R	An alternative measure of the ICT-Opportunity Index is studied in this paper.
25	2011	EU funded projects: from financial to economic analysis. Economia. Seria Management, 2011.	Radu, A.L. and M.C. Dimitriu	The EU funded project is done by Radu et al. In this project they studied from financial to economic analysis.
26	2012	Environmental efficiency evaluation based on data envelopment analysis: A review. Renewable and Sustainable Energy Reviews, 2012	Song, M	The achievements of the theoretical and practical basis of environmental policy analysis in order to study their works and point out the future possible research direction is investigated in this paper.
27	2013	DEA environmental assessment in a time horizon: Malmquist index on fuel mix, electricity and CO2 of industrial nations. Energy Economics, 2013	Sueyoshi, T. and M. Goto,	In this study, important empirical findings are found such as there is a time lag in technology innovation on electricity generation and CO2 emission reduction.
28	2013	A Guide to the Project Management Body of Knowledge (PMBOK® Guide) – Fifth Edition, 2013	Project Management Institute	In this research a Guide to the Project Management Body of Knowledge is written by Project Management Institute.
29	2014	Using data envelopment analysis to analyse the efficiency of primary care units. Journal of medical systems, 2014.	Deidda, M	Deidda used data envelopment analysis to analyse the efficiency of primary care unit, in this paper.
30	2014	Dynamic environmental efficiency evaluation of electric power industries: Evidence from OECD and BRIC countries. Energy, 2014.	Xie, B.-C	In this study, Dynamic environmental efficiency evaluation of electric power industries: Evidence from OECD (Organization for Economic Cooperation and Development) and BRIC (Brazil, Russia, India and China) countries is studied by Xie,B.

Table 8: Cont.

	Year of Publication	Topic	Author (s)	Summary
31	2014	Does environmental regulation affect energy efficiency in China's thermal power generation? Empirical evidence from a slacks-based DEA model. Energy Policy, 2014	Bi, G.-B	In this paper, a slack-based measure approach to investigating the relationship between fossil fuel consumption and the environmental regulation of China's thermal power generation is presented. The total-factor energy efficiency without considering environmental constraints is calculated and proposed an EPI. According to findings of paper is suggested some policy implications.
32	2015	Efficiency analysis with ratio measures. European Journal of operational research. (2015)	Olesen, O. B., Petersen, N. C., &Podinovski, V. V	In this research the efficiency analysis is done with ratio measures.
33	2015	Efficiency analysis of surgical services by combined use of DEA and gray relational analysis. Journal of medical systems, 2015	Girginer, N., T. Köse, and N. Uçkun	This study combined use of data envelopment analysis and gray relational analysis with an efficiency analysis of surgical services.
34	2017	A comprehensive review of (DEA) approach in energy efficiency. Renewable and Sustainable Energy Reviews (2017)	Mardani, A	In this paper, A comprehensive review of data envelopment analysis (DEA) approach in energy efficiency is studied by Mardani.
35	2017	Nonparametric Production Technologies with Multiple Component Processes. (2017)	Podinovski, V. V., Olesen, O. B., &Sarrico, C. S.	Podinovski et al. is studied the Nonparametric Production Technologies with Multiple Component Processes in this paper.
36	2018	A survey and analysis of the first 40 years of scholarly literature in DEA (2018)	Emrouznejad, A., & Yang, G	In this research, The first 40 years Scholary literature is surveyed and analyzed in DEA.
37	2018	(EPI). Palisades, NY: NASA .(SEDAC). 2018	EPI. YCELP. - CIESIN - Columbia University, and WEF	Yale Center for Environmental Law and Policy is studied Environmental Performance Index.
38	2019	An Estimation of the Efficiency and Productivity of Healthcare Systems in Sub-Saharan Africa: Health-Centred Millennium Development Goal-Based Evidence. Social Indicators Research, 2019	Ibrahim, M.D	Estimated efficiency of healthcare systems in SSA based on health focused MDGs is seeked in this paper and the technical efficiency and total factor productivity of these systems, and rank the annual performance of SSA's healthcare systems from 2010 to 2015 is estimated by using a robust (DEA) approach. Also applied Regression analysis to the determinants of healthcare system efficiency.
39	2019	Transnational resource generativity: Efficiency analysis and target setting of water, energy, land, and food nexus for OECD countries. Science of The Total Environment, 2019	Ibrahim, M.D	In this paper, the efficiency of Organization for Economic Co-Operation and Development (OECD) countries in terms of Water-Energy-Land-Food (WELF-Nexus) is evaluated to ensure sustainability and environmental viability for both present and future generations.
40	2020	Target setting in data envelopment analysis: efficiency improvement models with predefined inputs/outputs. OPSEARCH, 2020	Ibrahim, M.D	Target setting models that accommodate predefined desired output targets or predefined available inputs during efficiency improvement in data envelopment analysis are proposed in this paper.

Table 8: Cont.

	Year of Publication	Topic	Author (s)	Summary
41	2021	Data & Statistics. 2021	IRENA	Data & Statistics are presented by IRENA in 2021.
42	2021	SDG Indicators: Goal by Goal. 2021	Eurostat	Eurostat is presented SDG Indicators: Goal by Goal. 2021.
43	2021	World Development Indicators 2021	WBG	World Development Indicator in 2021 is presented in this research.

2.5 Literature Review of AHP Method

This section of our thesis provides a brief overview of the AHP Methodology. Many AHP studies have been published in the literature in recent years. At this part of review some of the important surveys about AHP are presented in Table 8, which is mentioned below.

Short research is conducted to gain an understanding of how these AHP sources were utilized in the past and to gain an understanding of their development. As a result of this assessment, some of the most valuable research is summarized in Table 9, which is mentioned below.

Table 9: A literature Review of AHP method

	Year of Publication	Topic	Author (s)	Summary
1	1977	New perspectives on organizational effectiveness. 1977	Goodman, P.S. and J.M. Pennings	The new perspectives on organizational effectiveness is studied in this paper.
2	1978	Measuring the efficiency of DMU. EUJ of OR, 1978	Charnes, A., W.W. Cooper, and E. Rhodes	In this research the efficient of DMUs are measured.
3	1985	Fuzzy hierarchical analysis, Fuzzy Sets Syst. 17 (1985)	J.J. Buckley	The fuzzy sets and Fuzzy Hierrarchical analysis are studied in this paper.
4	1994	Productivity growth, technical progress, and efficiency change in industrialized countries. The American economic review, 1994	Färe, R.	In this paper, Fare studied the productivity growth, technical progress, and efficiency change in industrialized countries.
5	1996	Applications of the extent analysis method on fuzzy AHP, Eur. J. Oper. Res.	D.-Y. Chang,	The applications of the extent analysis method on fuzzy AHP are studied in this paper.

Table 9: Cont.

	Year of Publication	Topic	Author (s)	Summary
6	2010	Creative thinking, problem solving and decision making, RWS Publications, 2010	T.L. Saaty	In this research, Saaty is studied for solution of problems and decision making with creative thinking.
7	2015	A fuzzy AHP methodology for selection of risk assessment methods in occupational safety, Int. J. Risk Assess. Manag.	A.F. Guneri, M. Gul, S. Ozgurle	A fuzzy analytic hierarchy process (AHP) methodology for selecting the best RAM in OS operations for SMEs is provided in this study. A Turkish woven-printed-carton labelling company was chosen to carry out this study application under four separate decision criteria namely: scope, practicality, cost and sensitivity is tested as a case study.
8	2017	Hybrid Probabilistic Risk Assessment Using Fuzzy FTA and Fuzzy AHP in a Process Industry, J. Fail. Anal. Prev	M. Yazdi,	The utility of fuzzy set theory and analytic hierarchy process to failure probability analysis in a case study is presented in this paper. The application of proposed model with a comparison of the results with conventional model is illustrated and selected a chemical process plant.
9	2018	Application of Pythagorean fuzzy AHP and VIKOR methods in occupational health and safety risk assessment: the case of a gun and rifle barrel external surface oxidation and colouring unit, Int. J. Occup. Saf. Ergon.	M. Gul,	A new approach for risk assessment in the field of OHS is proposed in this study and the PFAHP and FVIKOR into a risk assessment process is integrated. Weighting the risk parameters used in PFAHP. FVIKOR is then applied to prioritize the hazards. The applicability and validity of the proposed approach is demonstrated and performed a case study of a barrel external surface oxidation and coloring unit of a gun and rifle production facility.
10	2018	A new Fine-Kinney-based risk assessment framework using FAHP-FVIKOR incorporation, J. Loss Prev. Process Ind.	M. Gul, B. Guven, A.F. Guneri	In this paper, a new Fine-Kinney method is studied and illustrated the proposed method to evaluate of risks in the arms industry. The classical method and fuzzy technique is compared and an ideal solution (FTOPSIS) is discussed. Risk control policies to validate the effectiveness of their risk controls are determined.

Chapter 3

METHODOLOGY AND DATA COLLECTION

3.1 Dual Efficiency and Productivity Analysis of RE Alternatives of OECD Countries

The dual efficiency and productivity analysis of RE alternatives of OECD Countries framework examines the dual efficiency of bioenergy, renewable-hydro energy, solar energy, WE, and geothermal energy for selected OECD countries through an integrated model with energy, economic, environmental, and social dimensions. Two questions are explored, which RE alternative is more dual efficient and productive? Which RE alternative is best for a particular country? DEA is used for the efficiency evaluation and the global Malmquist productivity index is applied for productivity analysis.

3.1.1 RE Alternatives of OECD Countries

When governments aspire to attain sustainability, they look to RE as a key driver of long-term economic and social growth. (Bergasse, E. et al, 2013) There are a variety of RE options available. In addition, it is crucial to pick the correct one for the state because of the importance of investments and resource requirements. The demand for RE as a part of the global energy usage portfolios has been heightened by weather happen as a result of fossil fuel use. (Abolhosseini, S. et al, 2021)

Researchers have identified RE as a way to sustainable development to establish a sustainable environment. According to a forecast of the International Energy Agency (IEA), the proportion of renewable primary energy use will rise from 13% in 2011 to 18% in 2035. This will increase the share of RE in the energy mix

(IEA, 2021). RE is ranked second in terms of electricity production owing to the growth of hydropower and bioenergy (IEA, 2021). Institutions and the government are ramping support for RE technology to reduce the cost of production. Several studies argue that RE reduces greenhouse gas emissions and efficiently utilizes resources better than fossil fuel (Dowaki, K et al., 2015 and Shneider, U.A, et al., 2003). However, many still argue about the economic implications of RE while producing the needed power.

RE's environmental and economic challenges are still being worked out.(Florida, R, et al., 2001 and Welch, J.B et al., 2009). Decisions that balance the interests of shareholders with societal concerns about the environment are more likely to be long-term.(Walley, N et al., 1994). Welch and Venkateswaran used the term dual sustainable (effectiveness) to describe the attainment of environmental and financial sustainability at the same time in order to include WE's financial and environmental sustainability. (Welch, J.B et al., 2009) Simultaneously, comparable research into RE possibilities has yet to be carried out. A comparison of the different RE alternatives provides for a better educated RE choice. Effectiveness is a general metric that may be used for a variety of energy sources, including RE in this case. The effectiveness perspective and comparative grounds must be uniform among all RE options. To characterize the scenario and the analysis' goal, a set of indicators must be created. (Forsström, J. et al., 2011) The dual effectiveness contexts and comparative criteria are similar among all RE options in our analysis. As a result, comparative comparisons of RE options across time and between nations are possible. This analysis intends to address a gap in the RE literature by examining the dual comparative performance and effectiveness of RE options concerning generating electricity.

To improve efficiency, a benchmark for renewable energy options is needed, as well as comprehensive strategic recommendations for future development in renewable energy systems for different nations. To estimate the efficiency and productivity of the RE alternatives, this study uses DEA models and the Malmquist productivity index that are widely used in applied energy literature (Bi, G-B et al., 2014 and Kolagar, M et al., 2020). The major types of RE sources are; Hydropower, Biomass, Geothermal, Ocean, Solar, and Wind. (Short, W. et al. , 1995 and Szakaly, Z, et al. , 2021)

Hydropower is the most mature and largest source of RE for producing electricity (Manzano- Agugliaro, et al., 2013). Hydropower plants produce zero carbon emission as it converts the energy in flowing water into electricity (Mohammed, T., 2021). Biomass is one of the RE sources capable of making a significant contribution to the world's future energy supply (Ladanai,S., et al., 2009). Bioenergy is the energy derived from biomass (organic matter) such as plants and wastes (Ahorsu, R. et al., 2018). Some utilities and power generating companies with coal power plants have found that replacing some coal with biomass is a low-cost option to reduce emissions (EIA, 2021). In addition, using biomass in boilers reduces nitrous oxide emissions (Ozgen,S., et al., 2021). The most common biofuel is ethanol. Another biofuel is biodiesel, which can be made from vegetable and animal fats. Biodiesel can be used to fuel vehicles or as a fuel additive to reduce emissions (Madiwale,S.,et al., 2016). Geothermal energy is the natural heat within the earth that arises from the earth's core. To produce power from geothermal energy, wells are dug a mile deep into underground reservoirs to access the steam and hot water, which can then be used to drive turbines connected to electricity generators (Wong, K. V., et al., 2015). It has strong potential for continued expansion, especially in developing countries. The ocean can produce two types of energy: thermal energy from the sun's heat, and mechanical energy from the tides and waves (Mardani, A., et al., 2017). Warm surface water or boiling saltwater may both be used to power a turbine, which then powers a generating in an electrical conversion unit. (Wilberforce, T. et al., 2019) Solar Energy is the energy that comes from the sun. The energy is used by solar cells which convert sunlight into direct current electricity (Mardani, A., et al., 2017). The sun is a major source of inexhaustible free energy (i.e., solar energy). Currently, new technologies are being employed to generate electricity from harvested solar energy (Kabir, E., et al., 2018). WT transforms WE into electric energy without producing any waste. WE is a clean source of energy, and wind power is one of the lowest-priced RE technologies available (Sitharthan, R, et al., 2018). In the past few years, electricity generation from WE has grown all over the world.

3.1.1.1 Efficiency of RE Alternatives of OECD Countries

From an economic perspective, efficiency is the ratio of resources consumed to the results achieved, or ratio of input to output. (Goodman, P.S. and Penning, J.M., 1977) Efficiency analysis has grown in complexity because it should not only include economic perspective, but also environmental and social dimensions. (Radu, A.L. and Dimitriu, M.C, 2011) The outcomes of effectiveness analyses have provided policymakers with economics and micro/macro-level recommendations. This has aided politicians in making well-informed decisions that are appropriate for particular resources and public restrictions. (Cicea,C. et al., 2014) Economic and financial effectiveness is a broad definition of effectiveness that compares a system's intended output to the investment made in that system. (Banker, R. D. et al., 1984). Environmental effectiveness is from the other side, considers the environmental effects of society's resource consumption. (Ibrahim, M.D. et al., 2019) The combination of environmental and economic perspectives for efficiency results in dual effectiveness from an energy standpoint, with the energy dimensions as the primary determinant.

Energy-environmental effectiveness is a concept that refers to a system's environmental outcome in terms of increasing expected outcome (e.g., access to clean energy) while lowering negative environmental outcomes (e.g., carbon emissions) through sustainable solutions that are measured by their environmental issues. Environmental effectiveness has long been seen as a critical concern. (Song, M., et al., 2012). According to Edmonds and Reilly, decision-makers required global environmental effectiveness research for both environmental and energy growth to estimate or estimate future energy changes. (Edmonds, J. and reilly, J., 1983)

Extensive research has been carried out on RE. (Usman, O. et al., 2020 and Alola, A.A et al., 2019). Chien, and Hu (Chien, T. and Hu, J, 2007) compared the macro-economic efficiency of OECD and non-OECD in terms of RE. They demonstrate that growing the use of renewable energy increases efficiency while growing the use of conventional energy reduces environmental efficiency. Studies such as Ibrahim and Alola (Ibrahim and Alola, 2020) also supports the findings of Chien, and Hu (Chien, T. and Hu, J, 2007). Cicea et al. studied the effectiveness of RE development in European nations, focusing on RE supplies and generating as crucial elements. (Cicea,C. et al., 2014)

The sustainability of energy is a multi-dimensional system that includes economic, environmental, social, and basic energy variables. Various indicators have employed in numerous assessments to assess the effectiveness of the various sustainability of energy characteristics. To assess environmental effectiveness and

CO_2 emissions in the OECD, Zaim and Taskin looked at labor, capital stock, GDP, and carbon pollution. (Zaim, O. and Taskin, F., 2000) To examine the environmental economic efficiency in RE, Cicea et al. employed energy density, GDP per capita, GDP per RE invest as inputs and carbon pollution as an output. (Cicea,C. et al., 2014). Many studies have employed variables such as labor, net stock of fixed capital, materials, capacity, carbon pollution, and green power generation in the energy efficiency, environmental effectiveness, and economic efficiency of RE research. (Chien, T.; Hu, J, 2007, Xie, B., et al., 2014 and Huang, G. et al., 2021). See Xu et al. for a complete analysis of energy performance analysis using DEA. (Xu, T. et al., 2020)

When attempting to determine the dual effectiveness of RE options, the investment made in converting Alternative energy sources into useable energy is taken into account. When you consider the various stages of energy conversion, such as generation, storage, and transportation, as well as energy sustainable development parameters such as economic, environmental, and social dimensions with electricity production as a primary output, the inexpensive source of energy isn't the most effective or efficient.

3.1.2 Materials and Methods of RE Alternatives of OECD Countries

The dual efficiency of RE alternatives considering energy sustainability dimensions. To achieve the said objectives, the discussing of efficiency evaluation method and data sets are done.

3.1.2.1 Inputs and Outputs factors of RE Alternatives

Articles in the literature for RE efficiency analysis are void of at least one of the important dimensions of energy sustainability, or the environmental indicator used to represent the environmental dimension lacks robustness in its representation as required by the environmentally sustainable development goals (SDGs) target “SDG13, SDG14, and SDG15” (Mardani, A. et al, 2017 and Eurostat, 2021). In this study, all energy sustainability dimensions are represented in addition to a robust composite indicator for environmental dimension. For the economic dimension, Capital investment in each RE is considered.

Energy dimension, environmental dimension, and a social dimension are considered as outputs, while economic/financial resources are considered as input. Data for the analysis were sourced from International RE Agency (IRENA, 2021), World Bank (WBG, 1978), and Yale Center for Environmental Law and Policy (YCELP, 2021).

Inputs

- Economic Dimension: Capital investment (USD billions)- Investment in each RE source is considered as input into the technology. Capital investment includes all forms of financial support such as credit line, equity investment, grants, and guarantee towards RE transition (IRENA, 2021). Investment is made in expanding installed capacity and technologies required for RE to usable forms. Investment data is presented in billions of United States dollars (USD billions) at 2017 prices.

Output

- Energy Dimension: Electricity generation from respective Resources (GWh). This represents the amount of electricity generated from the respective Re alternative (IRENA, 2021).
- Environmental Dimension: ENVIRONMENTAL PERFORMANCE INDEX (EPI). EPI is a data-driven summary of the state of sustainability of a country. It is developed using 32 performance indicators across 11 issue categories

under two major is-sues-Environmental health and ecosystem vitality. Figure 1 presents the composition of EPI which makes it a comprehensive indicator for environmental dimension (YCELP, 2021). The EPI offers a powerful policy tool in support of efforts to meet the targets of the UN SDGs and to move society toward a sustainable future. The EPI score indicates which country is best addressing the environmental challenge that faces every nation while conducting their economic and infrastructural developments. This indicator helps understand environmental progress and refine policy recommendations (YCELP, 2021).

- Social Dimension: Access to clean fuels and technologies for cooking- this represents the proportion of the population with access to clean fuels and technology for cooking and domestic activities excluding kerosene. (WBG, 2021). This is a social component of RE to support everyday human activities and a major SDG.

The Composition of Environmental Performance Index is given in Figure 1.

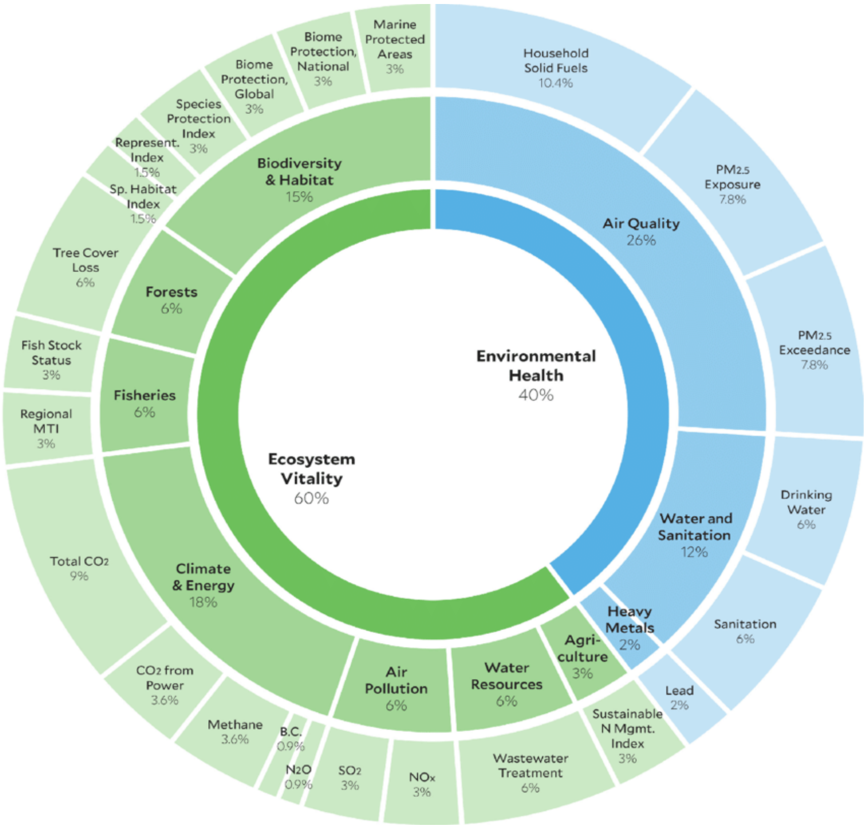

Figure 1: Composition of environmental performance index

3.1.2.2 DEA of RE

To analyze the dual efficiency of RE alternatives, the DEA technique is employed to accommodate the multi-dimension of RE system. DEA is an increasingly popular management tool. DEA was introduced by Charnes, Cooper, and Rhodes through the CCR model (Charnes, A. et al, 1978) and was modified by Banker, Charnes, and Cooper through the BCC model. (Banker, R. D., et. Al., 1984) It measures the efficiency of homogenous systems known as DMUs using frontier estimation.

DEA allows for the total factor efficiency of DMUs with multiple inputs and outputs comprising of measurement units that cannot be reduced to a common denominator criterion (Girginer, N. et al., 2015). DEA has grown in popularity in efficiency evaluation of both public and private sectors. In DEA there are a number of producers (DMUs).

In this study, RE systems for each country at a particular year each producer takes a set of inputs (Investment) and produces a set of outputs (electricity, environmental performance, and access to clean fuels and technologies). The systems take varying levels of inputs and give different levels of outputs. DEA attempts to determine which system is most efficient.

The fundamental assumption of DEA is that, if a system “A” produces “Y (A)” amount of output with “X (A)” number of inputs, then other systems should be able to do the same.

In the context of dual RE efficiency, if a particular RE utilizes a certain amount of investment, then the output should be compared with other RE alternatives since they are all receiving investment for their development. If a particular RE alternative has the better combination of outputs while receiving less investment, then it is more efficient than others.

To illustrate DEA frontier analysis technique, Figure 2 present a numerical illustration for one input one output production possibility set of system for simplicity. Each unit utilizes x amount of input and produces y amount of outputs; DMU(x,y). DMUs on the frontier are relatively efficient, and those enveloped are deemed inefficient. A(4,6), B(6,9), C(6,15), D(8,9), E(10,21), F(10, 18), and G(12, 15).

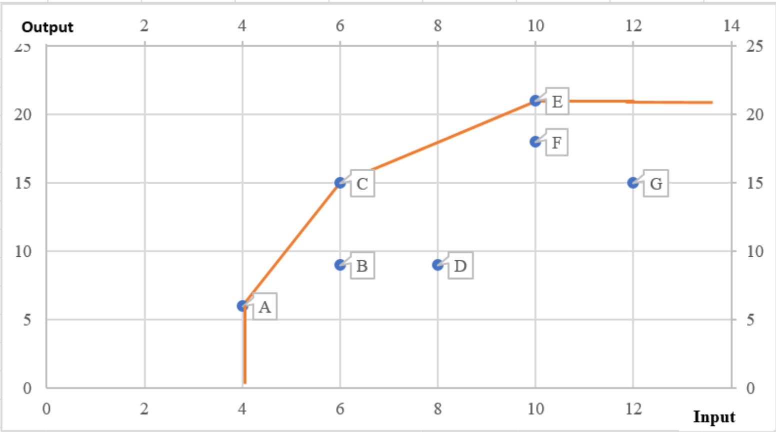

Figure 2: DEA efficiency frontier

A graph of the PRS of CCR model for two inputs one output is given in Figure 3.

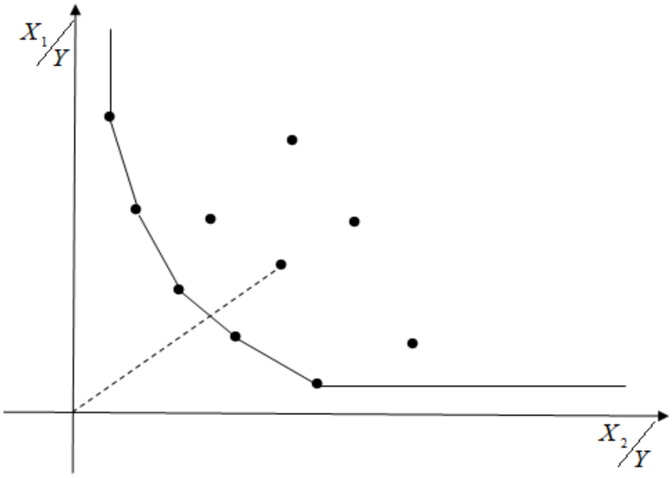

Figure 3: PRS of CCR model for two inputs one output.

Advantages of its application are as follows: it easily accommodates production systems with multiple inputs and outputs, it imposes no functional form for the production function, no endogeneity bias of traditional regression technique, more importantly, it identifies improvement targets for the inefficient units to achieve efficiency, thus providing useful insight into sources of inefficiency. (Ibrahim, M. D. et al, 2020 and Deidda, M. et al., 2014). From this perspective, the DEA approach is valuable for policymakers and management to understand their processes and identify if they are utilizing their resources appropriately by comparing them to the best practice (Ibrahim, M. D. et al, 2020).

The effective border is determined by comparing the homogeneous units against them self and the greatest measurement is accepted as the efficient frontier. Additional measurements are compared against the boundary. The boundary is found by looking for the most input/output combinations. The relative efficiency scores are reported between 0 and 1. DMUs with a score of 1 are regarded as efficient relative to other units whereas less than 1 is regarded as inefficient. DEA models comprise constant returns to scale (CRS) and variable returns to scale (VRS) models. The CRS models systems assumes that increase in inputs results in proportional increase in output level, while VRS models assume that an increase in the input does not necessarily result in a proportional increase in output. The VRS models show if a particular system is evaluated at increasing returns to scale (IRS), constant returns to scale (CRS), or decreasing returns to scale (DRS) (Banker, R. D., and Morey, R.C., 1986). A system is said to operate at IRS if a proportionate increase in its inputs results in more than a proportionate increase in output. Conversely, the DRS unit results in a less than proportionate increase in output (banker, R. D. & Thrall, R. M., 1992 and. Banker, R. D., & Morey, R.C., 1986).

The application of DEA in energy efficiency literature is well documented, with some linking it to environmental efficiency. However, only a few examine RE and make comparisons with other countries. OECD and non-OECD countries' RE and traditional energy with a focus on macro-economic efficiency is compared. (Chien, T. and HU, J., 2007) Efficiency analysis of RE investment in European countries was performed by using DEA (Cicea, C. et al., 2014).

This study evaluates the dual efficiency of RE among OECD countries. The analysis has two folds, first comparison between RE alternatives and across different countries. Two important conclusions can be made. First, the overall performance of each RE alternative can be estimated. Secondly, countries can reflect and see which RE alternative is most efficient for them since the comparison is made on homogenous grounds, i.e. investment, which covers installed capacity and other energy transformation processes, electricity generation from the RE alternatives, and environmental performance of the county.

To develop the model, consider a set of n observed DMUs, each $DMU_j,\ j=(1,\dots n)$ utilizes m inputs $x_{ij}=\left(x_{1j},\dots,x_{mj}\right)>0$ to produce s outputs $y_{rj}=\left(y_{1j},\dots y_{sj}\right)>0$. The DMU represents the RE alternative in a country. A country can utilize multiple RE alternatives simultaneously. For example; Mexico-Bioenergy, Mexico-Solar energy. Finland-WE, and Finland-Hydro power. We assume that all entries of these two arrays are positive. Overall, n DMUs and the Production Possibility Set (PPS) are as follows:

$$PPS=\{(x,y)\in\mathbb{R}_{+}^{m+s}: x \text{ can produce } y\}$$

The primal and dual forms of input and output-oriented Charnes-Cooper-Rhodes (CCR) model and Banker, Charnes, Cooper (BCC) model is given at Table 10 and Table 11.

Table 10: Charnes-Cooper-Rhodes (CCR) model

Input oriented CCR Model		**Output oriented CCR Model**	
Primal	**Dual**	**Primal**	**Dual**
Max $\sum_{r=1}^{s} u_r \boldsymbol{y}_{rk}$	$Min\ \theta_k$	$Min\ \sum_{i=1}^{m} v_i \boldsymbol{x}_{ik}$	$Max\ Z_k$
$\sum_{r=1}^{s} u_r \boldsymbol{y}_{rj} - \sum_{i=1}^{m} v_i \boldsymbol{x}_{ij} \leq 0$	$\sum_{ikj=1}^{m} \lambda_{jk} \boldsymbol{x}_{ij} \leq \theta_k \boldsymbol{x}$	$\sum_{i=1}^{m} v_i \boldsymbol{x}_{ij}$ - $\sum_{r=1}^{s} u_r \boldsymbol{y}_{rj} \geq 0$	$\sum_{j=1}^{n} \eta_{jk} \boldsymbol{x}_{ij} \leq \boldsymbol{x}_{ik}$
$\sum_{i=1}^{m} v_i \boldsymbol{x}_{ik} = 1$	$\sum_{j=1}^{n} \lambda_{jk} \boldsymbol{y}_{rj} \geq\ \boldsymbol{y}_{rj}$	$\sum_{r=1}^{s} u_r \boldsymbol{y}_{rj} = 1$	$z_k \boldsymbol{y}_{rk} - \sum_{j=1}^{n} \eta_{jk} \boldsymbol{y}_{rj} \leq 0$
$u_r, v_i\ \geq 0$	$\lambda_{jk} \geq 0$	$u_r, v_i\ \geq 0$	$\eta_{jk} \geq 0$

Table 11: Banker, Charnes, Cooper (BCC) model

Input oriented BCC Model		**Output oriented BCC Model**	
Primal	**Dual**	**Primal**	**Dual**
$Min\ \theta_k$	Max $\sum_{r=1}^{s} u_r \boldsymbol{y}_{rk} -\ u_k$	$Max\ Z_k$	$Min\ \sum_{i=1}^{m} v_i \boldsymbol{x}_{ik} -\ v_k$
$\theta_k \boldsymbol{x}_{ik} - \sum_{j=1}^{n} \lambda_{jk} \boldsymbol{x}_{ij} \geq 0$	$\sum_{r=1}^{s} u_r \boldsymbol{y}_{rj} - \sum_{i=1}^{m} v_i \boldsymbol{x}_{ij}$ - $u_k \leq 0$	$z_k \boldsymbol{y}_{rk} - \sum_{j=1}^{n} \eta_{jk} \boldsymbol{y}_{rj} \leq 0$	$+ \sum_{i=1}^{m} v_i \boldsymbol{x}_{ij}$
$\sum_{j=1}^{n} \lambda_{jk} \boldsymbol{y}_{rj} \geq\ \boldsymbol{y}_{rk}$	$\sum_{i=1}^{m} v_i \boldsymbol{x}_{ik} = 1$	$\sum_{j=1}^{n} \eta_{jk} \boldsymbol{x}_{ij} \leq \boldsymbol{x}_{ik}$	- $\sum_{r=1}^{s} u_r \boldsymbol{y}_{rj} -\ v_k$
$\lambda_{jk} \geq 0$	$u_r, v_i\ \geq \varepsilon > 0\ , u_k\ free$	$\sum_{j=1}^{n} \eta_{jk} = 1$	$\sum_{i=1}^{m} u_r \boldsymbol{y}_{rk} = 1$
		$\eta_{jk} \geq 0$	$u_r, v_i\ \geq \varepsilon > 0\ , v_k\ free$

3.1.2.3 Malmquist Productivity Index

DEA models analyze the relative efficiency of units, however, MALMQUIST PRODUCTIVITY INDEX (MPI) is used to estimate TOTAL FACTOR PRODUCTIVITY CHANGE (TFPC) examines the change in efficiency between period *t* and *t* + 1 (Chen , Y and Ali, A.I, 2004). MPI is a broadly used method to track the progress of systems performance in different sectors. (Ibrahim M.D, et al., 2019). Applied MPI for healthcare systems, utilized MPI for the environmental efficiency of industrialized countries. (Sueyoshi, T. and Goto, M, 2013) Similarly, Woo et al., (Woo, C. et al., 2015) analyzed the environmental efficiency of the agricultural sector of European countries using MPI. (Exposito, A and Velasco, F, 2020) MPI Eq. (3) refers to the ratio of the distance functions to measure their productivity (Caves, D.W, et al., 1982).

Table 12: The Optimistic DEA based on MPI

The optimistic DEA-based MPI	
$D_o^t(x_o^t, y_o^t) = Minimize\ \theta$ $\sum_{j=1}^{n} \lambda_j x_{ij}^t \le \theta x_{io}^t$, $i = 1, \dots, m,$ $\sum_{j=1}^{n} \lambda_j y_{rj}^t \ge y_{ro}^t,$ $r = 1, \dots, s,$ $\lambda_j \ge 0$ $j = 1, \dots, n.$	$D_o^t(x_o^{t+1}, y_o^{t+1}) = \text{Minimize}\ \theta$ $\sum_{j=1}^{n} \lambda_j x_{ij}^t \le \theta x_{io}^{t+1}$ $i = 1, \dots, m,$ $\sum_{j=1}^{n} \lambda_j y_{rj}^t \ge y_{ro}^{t+1},$ $r = 1, \dots, s,$ $\lambda_j \ge 0$ $j = 1, \dots, n.$
$D_o^{t+1}(x_o^{t+1}, y_o^{t+1}) = Minimize\ \theta$ $\sum_{j=1}^{n} \lambda_j x_{ij}^{t+1} \le \theta x_{io}^{t+1}$ $i = 1, \dots, m,$ $\sum_{j=1}^{n} \lambda_j y_{rj}^{t+1} \ge y_{ro}^{t+1},$ $r = 1, \dots, s,$ $\lambda_j \ge 0$ $j = 1, \dots, n.$	$D_o^{t+1}(x_o^t, y_o^t) = \text{Minimize}\ \theta$ $\sum_{j=1}^{n} \lambda_j x_{ij}^{t+1} \le \theta x_{io}^t$ $i = 1, \dots, m,$ $\sum_{j=1}^{n} \lambda_j y_{rj}^{t+1} \ge y_{ro}^t,$ $r = 1, \dots, s,$ $\lambda_j \ge 0$ $j = 1, \dots, n.$

Färe and Grosskopf using the geometric mean index extended the distance function to DEA-based MPI. (Färe, R. et al., 1994) MPI can be decomposed into TECHNICAL EFFICIENCY CHANGE (TEC) or EFFICIENCY CHANGE (EC) Eq. (2) and FRONTIER CHANGE (FC) or TECHNICAL CHANGE (TC) as illustrated by Eq. (3) (Färe, R. et al., 1994).

$$M_t^{t+1} = \left[\frac{D_0^t\left(x_0^{t+1}, y_0^{t+1}\right)}{D_0^t\left(x_0^t, y_0^t\right)} \frac{D_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)}{D_0^{t+1}\left(x_0^t, y_0^t\right)} \right]^{1/2} \tag{2}$$

$$TEC = \frac{D_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)}{D_0^t\left(x_0^t, y_0^t\right)} \tag{3}$$

$$FC = \left[\frac{D_0^t\left(x_0^{t+1}, y_0^{t+1}\right)}{D_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)} \frac{D_0^t\left(x_0^t, y_0^t\right)}{D_0^{t+1}\left(x_0^t, y_0^t\right)} \right]^{1/2} \tag{4}$$

From Eq. (2), efficiency improves if $M_t^{t+1} > 1$, efficiency remains the same if $M_t^{t+1} = 1$, and decreases if $M_t^{t+1} < 1$. Eq. (3) estimates the "catch up" effect of the DMU. It measures whether the DMU is closer or further away from the frontier in period *t* and *t+1*. FC or TC symbolizes technological progress or regression of the DMU between *t* and *t+1*. To overcome possible infeasibility in the DEA model and lack of circularity, Pastor and Lovell proposed the Global Malmquist index. (Pastor, J.T and Lovell, C.K, 2005) The output distance indices are measured concerning a global benchmark technology, defined as the convex hull of the set of all period's technologies. TEC or EC can be further decomposed into Pure Efficiency change (PEC) and Scale efficiency change (SEC) to perform a comprehensive analysis of the RE alternatives. This study employs VRS DEA model and global MPI.

3.2 An Extension of SFMEA for WT

WE have increased our electricity output tremendously during the last several years all over the world. RES is obtained from the ground and does not require any production techniques. When RES is used to generate power, CO2 emissions are kept to a minimum, and they cause less environmental damage when compared to traditional sources of energy. Typical RES are; hydraulic energy, wind power, solar power, geothermal power, biomass, biogas, wave power, and hydrogen power (Unal, 2006). WTs are the most rapidly developing kind of renewable energy since they convert WE into electricity without creating any waste.

FMEA investigations are used to collect components and process information, and then probable failure modes are discovered. Simultaneously time, the reasons and repercussions of each failure, as well as the present control procedure, should be determined. (Yazdi et al., 2017) In other words, expert judgment is used to assess detectability, likelihood, and degree of FM. To calculate each expert's capacity and provide the appropriate weights, the AHP approach was employed. The SFMEA tables which are filled by the experts are shown at Appendix 1. The O, S, D values of each expert are multiplied by the expert's weight and calculated. All weighted calculations relevant to SFMEA tables and experts are given in Appendix 1.

3.2.1 Wind Energy

WE is the most rapidly expanding form of RE. WE-generated energy is gaining a lot of attention as a viable alternative to traditional fossil, coal, and nuclear energy resources. (Anicic et al., 2016) WT converts WE into electricity without generating any waste. The wind industries are looking for strategies to anticipate the availability and reliability of installed WT with greater accuracy. In nature, FMEA is an inductive approach that may be used in all parts of failure analysis and prefers to collect data for risk management procedures. (Modarres, 1993).

WE are a clean flue resource and a household source of energy. WP is one of the most cost-effective renewable energy solutions. On existing farms or ranches, WT can be developed. Farmers and ranchers may keep working the field because the WT only uses a small portion of it. (Saidur et al., 2011) For the usage of the land, WP plant owners pay a fee to the farmer or rancher. This has a significant economic impact on rural communities. (Saidur et al., 2011).

When compared to alternative sources of RE, WE is clean, ecologically beneficial, and less expensive. When compared to petroleum-based energy plants, the use of WE might also help to minimize water use. (Saidur et al., 2011) WE have the least impact on the environment when compared to alternative energy sources. With proper wind turbine design, wind turbine planning, and wind farm location selection, many negative consequences may be reduced.

Wind farms are being built in a number of nations in order to generate electricity from renewable sources. WT generates power using a sustainable and environmentally benign resource: wind. Therefore, the dangers posed by wind farms have a significant impact on wind farm’s risk evaluations. Because of its wake effect, optimization of layout is particularly critical. (Herbet et al., 2007) Wind turbines should be placed according to the wind direction, and WF layout optimization is the process of determining the best WT sites within a WF. (Chen, 2013) The visual pollution impact of turbines, as well as the turbine blades' potential harm to surrounding species, should be considered during the placement choice. (Birds have been killed in the past by flying into the rotors.) (Saidur et al., 2011)

3.2.2 FMEA

FMEA is a strategy for detecting predicted FMs of a product or process and planning for their eradication that mixes technology and human experience. (Besterfield, 2003) FMEA investigations are used to collect components and process data, and then probable FMs are discovered. At the same time, the reasons, and repercussions of each failure, as well as the present control procedure, should be determined. (Yazdi et al., 2017) In other words, expert judgment is used to assess the detectability, likelihood, and severity of FM.

The FMEA is focused on the subsystems of WT. Therefore, in this study, we suggest evaluating wind turbine system techniques using Smart FMEA, which is a mix of standard FMEA, DEA, and AHP. Using FMEA procedures, a risk analysis is performed to enhance, manage, and identify hazards in wind energy facilities. The economic and financial, social and environmental, construction and management, political, and technological hazards related to WP facilities are all categorized. By using FMEA techniques, the risk priority numbers of power plants are calculated, and a risk table is constructed.

The traditional FMEA determines the RP of FMs through the RPN, which is the product of the O, S, D of a failure (Wang, Chin, Poon and Yang, 2009). That is, RPN = O x S x D; FMEA employs a scale of one to ten to assess the likelihood of occurrence, non-detection, and severity. (Chang, Wei and Lee, 1999).

FMEA describes critical early corrective steps in a system, product, process, or service that will avoid defects and mistakes before happening and impacting the consumer. Therefore, for such a number of reasons, the crisp RPNs have been heavily criticized. (Wang, Chin, Poon and Yang, 2009). Some of the more serious complaints include, but are not limited as follow:

- It is not taken into account the relative value of O, S, and D. The importance of the 3 risk variables is considered to be equal. When it comes to practical implementation of FMEA, it might not be the case.
- While various combinations of O, S, and D may generate the same RPN number, the risk consequences are likely to be significantly different. For instance, two events with the values of 6, 3, 5 and 5, 6, 3 for O, S, and D, respectively, have the same RPN value of 90. Therefore, the hidden risk consequences of the two occurrences will not be the same. It might result in wasted money and time, even, in rare situations, an unnoticed high-risk occurrence.
- The RPN level has several statistical parameters that are counterintuitive. It is generated just from three criteria, mostly in safety, because the traditional RPN technique does not account for indirect components relationships.

Realism should not be required while performing an FMEA for the purpose of a safety evaluation if the evidence is inaccurate and sparse. As a result, asking an analysis or a specialist to provide ratings from one to ten, for the many elements under consideration (as done in the RPN technique) would create a misleading and unrealistic image. (Pillay, Wang, Jung, Kwon, Loughran, l'Anson, Wall and Ruxton, 2001). However, this improves the calculation, translating the possibility into a different rating system and then calculating the multiplying of scores obtained might cause issues.

For each FM, the severity of the consequence of failure, the likelihood of occurrence, and the efficiency of detection are RPN functional variables, which are computed by multiplying these three variables. RPN is a risk assessment tool that helps you discover major FMs in your design or process. (Kiran, 2017)

The formula of RPN is given as follow;

$$RPN = O\ X\ S\ X\ D \tag{5}$$

S is the severity of the effect of failure, O is the probability of occurrence, and D is the ease of detection.

The RPN parameters are measured using the scores from one to ten according to FMEA ratings S, D, O tables where number one and ten show the least and the most important risk factor, respectively. The RPN values range from 1 (absolute best) to 1000 (absolute worst). A failure mode with a higher RPN has a higher priority and is assumed to be more important.

The meaning and FMEA ratings for severity, detection, and probability occurrence of a failure are given in Table 13, and 14, respectively. The failure probability and FMEA rating for occurrence of a failure is given in Table 15 and the risk probability number and decision table is given in Table 16.

Table 13: FMEA ratings for severity of a failure (S) (Liu et al., 2011)

Severity effect	**Meaning**	**Rating**
None	No effect.	1
Very minor	Cosmetic defect in finish, fit and finish/squeak or rattle item that does not conform to specifications. Defect noticed by discriminating customers.	2
Minor	Cosmetic defect in finish, fit and finish/squeak or rattle item that does not conform to specifications.Defect noticed by average customer.	3
Very Low	Cosmetic defect in finish, fit and finish/squeak or rattle item that does not conform to specifications. Defect noticed by most customers.	4
Low	Item operable, but comfort/convenience item(s) operable at reduced level of performance. Customer experiences some dissatisfaction.	5
Moderate	Item operable, but comfort/convenience item(s) inoperable. Customer experiences discomfort.	6
High	Item operable, but at reduced level of performance. Customer dissatisfied.	7
Very high	Item inoperable, with loss of primary function.	8
Hazardous with warning	Very High severity ranking when a potential failure mode affects safe operation and/or involves noncompliance with government regulations with warning.	9
Hazardous without warning	Very High severity ranking when a potential failure mode affects safe operation and/or involves noncompliance with government regulations without warning.	10

Table 14: FMEA ratings for detection of a failure (D) (Liu et al., 2011)

Detection	Meaning	Rating
Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode.	1
Very high	Very High chance the design control will detect a potential cause/mechanism and subsequent failure mode.	2
High	High chance the design control will detect a potential cause/mechanism and subsequent failure mode.	3
Moderately high	Moderately high chance the design control will detect a potential cause/mechanism and subsequent failure mode.	4
Moderate	Moderate chance the design control will detect a potential cause/mechanism and subsequent failure mode.	5
Low	Low chance the design control will detect a potential cause/mechanism and subsequent failure mode.	6
Very Low	Very Low chance the design control will detect a potential cause/mechanism and subsequent failure mode.	7
Remote	Remote chance the design control will detect a potential cause/mechanism and subsequent failure mode.	8
Very remote	Very remote chance the design control will detect a potential cause/mechanism and subsequent failure mode.	9
Absolutely impossible	Design control will not and/or cannot detect a potential cause/mechanism and subsequent failure mode; or there is no design control.	10

Table 15: FMEA ratings for Occurrence of failure (O) (Liu et al., 2011)

Probability of occurrence	Failure probability	Rating
Very Low : Inevitable Error	More than 1 / 2	10
Very Low : Inevitable Error	1/3	9
High : Repeatedly Error	1/8	8
High : Repeatedly Error	1/20	7
Medium : Causal Error	1/80	6
Medium : Causal Error	1 / 400	5
Medium : Causal Error	1 / 2 000	4
Low : Relatively Less Error	1 / 15 000	3
Low : Relatively Less Error	1 / 150 000	2
Very Low : Improbability Error	Less than 1 / 15 000	1

Table 16: Risk priority number (RPN) (Liu et al., 2011)

Number	RPN	Decision
1	1 - 50	Low risk
2	50-100	Moderate risk
3	100-200	High risk
4	200-1000	Very high risk

3.2.2.1 Risk of generating Electricity from WP Energy

Risks of generating electricity from WP energy can be categorized as feasibility study risks, technological risks, ergonomics risks, environmental risks, and technical risks. In this study, we determined $R_{x\text{-}y\text{-}z}$ which means that failure Z of risk Y into category X.

Failure modes for Feasibility studies are identified as choosing an inappropriate wind farm area ($R_{1Feasibility}$), choosing an inappropriate wind turbine ($R_{2Feasibility}$), wind turbine sitting mistake ($R_{3Feasibility}$) and unexpected investment cost ($R_{4Feasibility}$).

Transportation problems, insufficient WP (Powerless wind), bird deaths, diminishing of cultivatable areas, terrorism, and civil unrest and war are cause of failure which is identified as choosing an inappropriate wind farm area.

- $R_{1\text{-}1\ Feasibility}$: Transportation problem. A transportation issue might arise during the building and operation of a WF. This failure can result in lost time, unanticipated costs, and traffic collisions. Potential transport hazards include traffic accidents, driver-induced accidents, long-distance travel, causes of way, and products rollover.
- $R_{1\text{-}2\ Feasibility}$: Insufficient WP (Powerless wind). Inadequate WP is a concern that might result in lower capacity and investment return. Wind speed alteration is a type of danger that can arise when typical wind speeds in the

area where WTs are built are insufficient to create economically viable power outputs, and the power output falls below the limit necessary to generate energy.

- $R_{1\text{-}3\ Feasibility}$: Bird deaths. When WT is put in the migration pathways of incoming birds, it poses a concern.
- $R_{1\text{-}4\ Feasibility}$: Diminishing of cultivatable areas. It is a type of danger that might emerge when WT takes over big regions.
- $R_{1\text{-}5\ Feasibility}$: Terrorism. It has to do with taking safeguards to both mitigate and avoid the impact of any acts of terrorism on RE facilities. RE facilities must, in principle, be unpleasant and deterrence to terrorist activities and attacks.
- $R_{1\text{-}6\ Feasibility}$: Civil unrest and war. Overseas firms are constantly intimidated by the prospect of expropriation and nationalization policies of governments. Investors' decisions are also influenced by global political disputes and wars. The energy industry is essential not just because of national politics, but also because of global politics. Wars are waged, military coups are planned, and nations are conquered all over the world to control energy supplies, which is a well-known truth. Strikes, civil unrest, insurrection, political instability, change in government, and even civil conflict are all hazards that are linked. (Dumlupınar Üniversitesi Sosyal Bilimler Dergisi EYİ, 2013)

Disagreeable turbine selection is cause of failure, which is identified as choosing an inappropriate wind turbine.

- $R_{2\text{-}1\ Feasibility}$: Disagreeable turbine selection. It may result in needless costs; thus the most suitable windmill should be selected based on the estimated potential study. Selecting an unsuitable windmill is a danger that can arise when a windmill is selected that is unprofitable or does not meet the criteria for the location where the facility will be built.

Suboptimal sitting of wind turbine into the wind farm and difficulties of emergency evacuation are the cause of failure, which is identified as wind turbine sitting mistake.

- $R_{3\text{-}1\ Feasibility}$: Sitting mistake of WT. Windmill placement in the wind farm is not optimum.
- $R_{3\text{-}2\ Feasibility}$: Difficulties of an emergency evacuation.

Calculating mistakes of investment costs, foreign exchange risk, credit risk, inflation risk, electricity price risk, expensive spare parts and change of law and regulations are cause of failure which is identified as unexpected investment cost.

- $R_{4\text{-}1\ Feasibility}$: Calculating mistake of investment cost. During the investment in a WF, there is a chance that a technical, cost, design, or operating error will occur.
- $R_{4\text{-}2\ Feasibility}$: Foreign exchange risk. It may be defined as the risk of financial loss or values as a result of fluctuations in the local currency market in relation to foreign currency. Foreign currency risk manifests itself in the form of profits and losses on a company's balance sheet or investment account because of fluctuations in foreign exchange rates.
- $R_{4\text{-}3Feasibility}$: Credit risk. It's the risk that the borrowers won't be able to meet his commitments. The payment capability of the borrowers assessed according to the credit facilities, calculating what more debt the borrower can repay. Due to the dangers posed by natural/climatic catastrophes, owners in the energy industry, in especially, have trouble repaying their loans.
- $R_{4\text{-}4Feasibility}$: Inflation risk. It refers to the possibility of an unfavorable rate of

return for investment. The decreasing buying power of income as a result of rising going rates affects the effectiveness of stock holdings.

- $R_{4\text{-}5Feasibility}$: Electricity price risk. The risky government-established pricing for RE plants also ensures owners' purchasing power at this rate. Furthermore, though improbable, here remains the chance of a price adjustment or guaranteed invalidation. The chance of current loan failure is the most significant result of this.
- $R_{4\text{-}6Feasibility}$: Change of law and regulations. It is a danger associated with the country's termination of the loans, capital subsidy, and financial help to renewable energy plants. As a result, potential changes in Turkish regulations relating to RES must be closely studied and examined. The stability of electricity pricing rates, in particular, is critical for RE installations.

Failure modes for technological are identified as technical and engineering design mistakes and the advancement of alternative technologies may render other energy sources more feasible.

Wrong capacity calculation and wrong turbine design are cause of failure which is identified as technical and engineering design mistakes. Technical and engineering design mistakes is generally occurring before the construction during the design process.

- $R_{1\text{-}1Technological}$: Wrong capacity calculation is cause of capacity and expense.
- $R_{1\text{-}2Technological}$: Wrong turbine design is cause of capacity and expense.

Advancement of alternative technologies may render other energy sources more feasible is the risk of affecting all energy plants producing same or different types of energy. Those investors that develop or utilize better technology will have certain competitive advantages over their rivals.

- $R_{2\text{-}1Technological}$: Wrong technology selection is cause of capacity and expense.

Failure modes for ergonomics are identified as working non-ergonomic conditions and working in confined spaces.

- $R_{3\text{-}1\ Ergonomics}$: Working in non-ergonomic conditions is the risk related to results as unhealthy and physically.
- $R_{3\text{-}2\ Ergonomics}$: Working in confined spaces is the risk related to inefficiently working.

Failure modes for environmental is identified as fire risk, icing risk, natural disaster, freezing of equipment's fuel, gas emission, geothermal waste risk, noise, harming of third parties, work accidents because of weather conditions and emergency evacuation for workers.

Natural disaster is a kind of risk defined as physical damages and losses that may happen during the construction or operating of energy plants due to natural disasters such as earthquakes, floods hurricanes, storms.

- $R_{1\text{-}1Environmental}$: Natural disaster is the risk related to devastation.

Fire and explosion are a kind of risk that may happen due to human-triggered accidents and mistakes, natural disasters, terrorist attacks etc. during construction or operational steps. In the event of an emergency such as a fire or lightning strike, especially if the person working on the tower cannot exit from the tower, it should go down from the outside of the tower.

- $R_{2\text{-}1Environmental}$: Electrical failure is the risk related to fire risk.
- $R_{2\text{-}2Environmental}$: Strike of lightning is the risk related to fire risk.

Harming of third parties is a risk that may happen when fire and explosions, terrorist attacks; natural disasters in energy plants may give physical or financial harm to third parties.

- $R_{3\text{-}1Environmental}$: Harming of third parties is a risk related to health problems.

Noise is a risk, which is produced by WT, is a contentious issue. Prolonged exposure to industrial noise can elevate stress, increase workplace accidents rates, and stimulate aggression and other anti-social behaviors among humans.

- $R_{4\text{-}1Environmental}$: Noise is a risk related to an environmental problem.

Gas emission risk may result in global warming and disturbing the ecosystem since geothermal energy plants emit small amounts of CO2, NOx, and SOx.

- $R_{5\text{-}1Environmental}$: Gas emission is a risk related to environment.

Geothermal waste risk can emerge when geothermal facility waste reaches a level that is harmful to the planet and causes environmental issues. Because of the high temperature and pressure, geothermal fluids include a variety of chemical compounds within their composition.

- $R_{6\text{-}1Environmental}$: Geothermal waste risk is related to environmental problems.

Ice is a problem that can develop, particularly in the wintertime; freezing on the rotor or the blades can reach heights of 2 m and spin 100 m.

- $R_{7\text{-}1Environmental}$: Icing is a risk related to environmental accidents.

Emergency evacuation for workers is a risk that happens when a worker works alone in the turbine, working without personal protective equipment against falls from a height, and working without educated personnel and is unaware of management.

- $R_{8\text{-}1Environmental}$: Emergency evacuation for workers is a risk that happens when a worker works single in turbine.

Work accidents because of weather conditions are a kind of risk which is cause of health problems and waste time.

- $R_{9\text{-}1Environmental}$: Work accidents are risk related to environmental accident.

Freezing of equipment's fuel is a risk, which may occur especially in winter; the icing on the equipment's fuel can freeze and equipment can break, also can cause of stop working.

- $R_{10\text{-}1Environmental}$: Freezing of equipment's fuel is a risk related to an environmental problem.

Failure modes for technical are identified as an accident, repair/maintenance, and a component of WT.

Fall from high, difficulties of emergency evacuation, electrical shock, fall of material during lifting, moving materials crash, manual handling, rollover of carrier vehicle, rollover of shipment, driver borne problems and operator borne problems are the cause of failure which is identified as Accident.

- $R_{1\text{-}1Technical}$: Fall from high. Working without safety clothing, in inclement weather, in hazardous situations, and working unknowingly causes a person to fall from a great height.
- $R_{1\text{-}2Technical}$: Difficulties of emergency evacuation. It occurs when a person is working alone and is out of contact with management as a result of a technological malfunction.
- $R_{1\text{-}3Technical}$: Electrical shock. Workplace accidents occur as a result of sloppy work, operating when electricity is turned on, operating without safety clothing, an unregulated earth system, and reckless excavation work on an electrical line.
- $R_{1\text{-}4Technical}$: Fall of material during lifting. It is possible that a work accident will occur as a result of a non-specialist winch driver, operating without proper technical maintenance, or operating carelessly as a result of technical failure.

- $R_{1\text{-}5Technical}$: Moving materials crash. Workplace accidents occur as a result of restricted spaces and reckless labor.
- $R_{1\text{-}6Technical}$: Manuel handling. It occurs as a result of a health issue or a workplace accident.
- $R_{1\text{-}7Technical}$: Rollover of carrier vehicle. Workplace accidents occur as a result of restricted spaces, irresponsible driving, and inclement weather.
- $R_{1\text{-}8Technical}$: Rollover of shipment. Traffic accidents occur as a result of non-conforming driving, workplace accidents as a result of limited space, reckless labor, and inclement weather.
- $R_{1\text{-}9Technical}$: Driver borne problems. It happens when driver is tired and driving carelessly.
- $R_{1\text{-}10Technical}$: Operator-borne problems. It happens when operator is uneducated and without careless.

Unexpected maintenance and repair, unexpected extension of periodic maintenance periods, delay in procurement of equipment, fire and electric shock is cause of failure which is identified as repair/maintenance.

- $R_{2\text{-}1Technical}$: Unexpected maintenance and repair. Unplanned maintenance and repairs occur because of poor planning or worker errors and accidents. Due to unscheduled maintenance, power generation may be stopped and/or the facility may be temporarily closed.
- $R_{2\text{-}2Technical}$: Unexpected extension of periodic maintenance periods. It has to do with the lengthening of maintenance intervals as a result of technical and design flaws, as well as employee accidents and blunders. Power facilities are maintained according to predetermined timetables and durations.
- $R_{2\text{-}3Technical}$: Delay in the procurement of equipment. It creates a construction

delays schedule owing to several factors such as delays in the acquisition of imported machinery and/or equipment.

- $R_{2\text{-}4Technical}$: Fire. During the building or operational phases, accidents and blunders may occur.
- $R_{2\text{-}5Technical}$: Electric shock. It is a type of danger that can occur during installation or operating processes as a result of human-caused mishaps and blunders, natural catastrophes, terror attacks, and so on.

Structure failures, rotor blades failures, mechanical brake failures, drive train failures, generator failures, gearbox failures, yaw system failures, sensor failures, hydraulic system failures, electrical system failures, control system failures, hub failures, and safety blade numbers is cause of failure which is identified as component failure.

- $R_{3\text{-}1Technical}$: A structure failure is a risk that happen when wind is high and this failure cause of over speed. Failure of any part or assembly that forms part of a supporting structure.
- $R_{3\text{-}2Technical}$: A rotor blades failure is a risk that happens grid failure that cause of overload.
- $R_{3\text{-}3Technical}$: Mechanical brake failures is a risk that happens lightning that cause of noise.
- $R_{3\text{-}4Technical}$: Drive train failures are a risk that happens icing that cause of Vibration.
- $R_{3\text{-}5Technical}$: Generator failures are a risk that component wear of failure that causing follow-up damage.
- $R_{3\text{-}6Technical}$: Gearbox failures are a risk that happens malfunction of control system that cause of reduced power.

- $R_{3-7Technical}$: Yaw system failures are a risk that happens to loosen of parts that cause plant stoppage.
- $R_{3-8Technical}$: Sensor failures are a risk that happens as other causes that cause of other consequences.
- $R_{3-9Technical}$: Hydraulic system failures are a risk that happen cause unknown.
- $R_{3-10Technical}$: Electrical system failures are risk of technical failure mode. Failure of a part or assembly as a result of an electrical defect. Failure of a part or assembly with a high resistance to the flow of electrical current, resulting in leakage of current from a conductor.
- $R_{3-11Technical}$: Control system failures are risk of technical failure mode.
- $R_{3-12Technical}$: Hub failures are risk of technical failure mode.
- $R_{3-13Technical}$: Safety blade numbers are risk that happens mistake of assembly that cause of failure.

Table 17: Failure modes and effects table for wind turbine.

Sub system	Failure modes	Cause of failure	Effects
Feasibilty Study	Choosing an inappropriate wind farm area	Transportation problem	Waste time and energy
		Insufficient wind power (Powerless wind)	Capacity and Profit
		Bird deaths	Environment
		Diminishing of cultivatable areas	Environment
		Terorism	Profit and cost
		Civil unrest and war	Cost
	Choosing an inappropriate wind turbine	Disagreeable turbine selection	Capacity and Profit

Table 17: Cont.

Sub system	Failure modes	Cause of failure	Effects
Feasibilty Study	Wind turbine sitting mistake	Suboptimal sitting of wind turbine into the wind farm	Capacity and Profit
		Difficulties of emergency evacuation.	Health
	Unexpected investment cost	Calculating mistake of investment costs	Cost
		Foreign exchange risk	Cost
		Credit risk	Cost
		Inflation risk	Cost
		Electricity price risk	Cost
		Expensive spare parts	Cost
		Change of law and regulations.	Management
Technological	Technical and Engineering design mistakes	Wrong capacity calculation	Capacity and cost
		Wrong turbine design	Capacity and cost
	Advancement of alternative technologies may render other energy sources more feasible	Wrong technology selection	Capacity and cost
Ergonomics	Working non ergonomic conditions	Health problems	Health
	Working in confined spaces	Inefficiently working	Health and cost
Environmental	Fire risk	Electrical failures.	Cost
	Fire risk	Strike of lightning	Cost
	Icing risk	Injury of 3rd person	Health
	Natural disaster	Devastate	Cost
	Freezing of equipments's fuels	Broken of quipment	Cost
	Freezing of equipments's fuels	Waste time	Cost
	Gas emission	Environmental pollution	Environment

Table 17: Cont.

Sub system	Failure modes	Cause of failure	Effects
	Noise	Health problems	Environment
	Harming of 3rd parties	Health problems	Health
	Work accidents because of weather conditions	Health problems	Cost
		Waste time	Cost
	Emergency evacuation for workers	Dangerous situation	Health
Technical	Accident	Fall from high	Health
		Difficulties of emergency evacuation	Health
		Electrical Shock	Health
		Fall of material during lifting	Health
		Moving materials crash	Cost
		Manuel handling	Health
		Rollover of carrier vehicle	Cost
		Rollover of shipment	Cost
		Driver borne problems	Health
		Operator borne problems	Health
	Repair /Maintenance	Unexpected maintenance and repair	Cost and waste time
		Unexpected extension of periodic maintenance periods	Cost and waste time
		Delay in procurement of equipment	Cost and waste time
		Fire	Cost
		Electric Shock	Cost
	Component failure	Structure failures.	Cost
		Rotor blades failures	Cost
		Mechanical Brake failures.	Cost
Technical	Component failure	Drive train failures.	Cost
		Generator failures.	Cost
		Gearbox failures.	Cost
		Yaw system failures.	Cost
		Sensor failures.	Cost
		Hydraulic system failures.	Cost
		Electrical system failures.	Cost
		Control system failures.	Cost

3.2.3 Analytical Hierarchy Process

The AHP, developed by Thomas Saaty in 1980, is a useful method for solving with difficult decisions, and it may help the decision maker define objectives and making the optimal choice. The AHP takes into account both quantitative and qualitative components of a choice by reducing complicated judgments to a series of pair - wise comparisons and then combining the findings. Furthermore, the AHP includes a beneficial approach for assessing the reliability of the expert judgments, therefore eliminating expert bias.

The AHP can be implemented in three simple consecutive steps:

1. Calculating the criteria weight's vectors.
2. Calculating the alternative score matrix.
3. Option ranking.

The next sections will go through each stage in depth. It is anticipated that m evaluation criteria will be used and that n alternatives will be reviewed. There will also be an introduction to a valuable approach for determining the results' dependability.

3.2.3.1 Expert Judgment

Judgment of expert is a process in which a decision is made based on a set of criteria and/or competence gained in a different knowledge area, field of application, or product area, a field, or industry, for example. (Project management Institute, 2013) Expertise is supplied in this study by specific education, experience, age, and training. A standard technique was chosen as a panel of weighting specialists.

In this study, experts are selected from different wind farms and also the specific educations, experience, authority. and responsibility of them are all differ to look at a wind farm in perspective. For the management, feasibility studies, environmental, ergonomically, technological, and technical issues we decide to take expert opinion from a plant manager who is responsible for wind farm, from technical support division and a project manager, who is working in a big WP farm's construction society for more than 10 years with BS qualification. Because manager's opinions are differed from employers. Manager's aims all same, to get profit and to reduce cost. We also have two of engineer opinion both of them are working in a big WP farm's construction society for more than 10 years with BS qualification and also one of our expert is a technical person at WP industry.

All of our experts are working in wind power industry and none of the experts are working in same farm. All of them are from different region of Turkey so their opinions are different to each other according to their farms and region conditions. The farm's region is important for instance east part of Turkey and west part of Turkey has totally different characteristics as weather, temperature, wind direction, terrorism, environmental effects, regulations, geographical positions, etc. In this case terrorism can be very big problem in east part of Turkey but it is not such a big problem for west but and also icing is a big problem for east part of Turkey because of the cold weather conditions but it does not affect west part as well as east part. In this case the obtaining the opinions of experts from different wind farms and various specialists have been very beneficial for our study.

3.2.3.1.1 Computation for Weighting of Experts

It is proposed that a technique based on group decision making be used for collecting and weighing expert information or viewpoints, as well as determining the ultimate consensus for a group of experts. In decision-making, various specialists examine the same problem in various ways in order to arrive at diverse conclusions for making decisions about the same circumstance. As in literature, a simple average strategy based on age, personal experience, work duration, and educational level has been examined for expert weighting. However, this strategy does not appear to be very effective. (G.Kabir et al., 2015)

It is preferable to employ multi-expert views as an independently reference in order to acquire far more dependable results as an output of any risk assessment methodologies. The weighing of experts picked in a diverse manner is done using a conventional technique for this study. (Yazdi et al., 2018) The job tenure, education, experience and of course paradigm shift is given as follow for each expert.

Expert 1: A Plant manager, who is responsible for wind farm, from technical support division.

Expert 2: A project manager, who is working in a big WP farm's construction society for more than 10 years with BS qualification.

Expert 3: Engineer, who is working in a big WP farm's construction society for more than 10 years with BS qualification.

Expert 4: Engineer, who is working in a big WP farm's construction society for more than 10 years with BS qualification.

Expert 5: Technical person at WP Industry.

To calculate each expert's capacity and provide the appropriate weights, the AHP approach was employed.

Consistency Index (CI) The scalar x is computed as the mean of the elements of the vector whose j th element is the percentage of the j th element of the vector $A * W$ to the corresponding element of the vector w, where max is the principal Eigen value and n is the size of the matrix.

Then,

$$CI = \frac{\lambda \text{max} - \text{n}}{\text{n} - 1} \tag{6}$$

CI=0 should always be obtained by a fully consistent decision-maker, although tiny amounts of inconsistency can be tolerated. If, in particular,

$$\frac{CI}{RI} < 0.1 \quad (7)$$

The discrepancies are manageable, and the AHP should provide a trustworthy result. In (7) RI is the random index, i.e. the consistency index when the entries of A are fully random. The values of RI for small problems (m ≤ 10) are shown in Table 18.

Table 18: Random consistency index RI

M	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.525	0.882	1.115	1.252	1.341	1.404	1.452	1.484

Table 19: Expert weight

EXPERTS	FARM MANAGER	PROJECT MANAGER	ENGINEER 1	ENGINEER 2	TECHNICIAL PERSON
WEIGHT	0,47	0,301	0.124	0.058	0,046

AHP method was used to compute each expert's capability and assigning the respective weights. The system of expert information is illustrated in Table 20. In this regard, the following weights 0.47, 0.301, 0.124, 0,058 and 0.046 are given to E1, E2, E3, E4 and E5, respectively.

3.2.4 Computing SFMEA

SFMEA is a strategy for identifying and focusing on WT subsystems. While using Smart FMEA on WT, it analyzes the consequences of decision factors and it investigates the interaction between WT components that would be affected by downtime, as well as cost criticalities associated with WT type and location, employing AHP and DEA with crisp modeling.

Table 20: Computing RPN value by using a weighting of Experts for Wind Turbine.

Failures	RPN	Failures	RPN
Transportation problem	75,135	Health problems	127,574
Insufficient wind power (Powerless wind)	206,354	Waste time	119,408
Bird deaths	103,426	Dangerous situation	153,648
Diminishing of cultivatable areas	28,8	Fall from high	83,618
Terorism	109,436	Difficulties of emergency evacuation	48,244
Civil unrest and war	187,972	Electrical Shock	85,7
Disagreable turbine selection	118,858	Fall of material during lifting	177,202
Suboptimal sitting of wind turbine into the wind farm	163,718	Moving materials crash	127,968
Difficulties of emergency evacuation.	100,354	Manuel handling	86,84
Calculating mistake of investment costs	271,54	Rollever of carrier vehicle	190,732
Foreign exchange risk	358,362	Rollever of shipment	141,248
Credit risk	176,692	Driver borne problems	190,48
Inflation risk	355,676	Operator borne problems	152,778
Electricity price risk	320,6	Unexpected maintenance and repair	294,968
Expensive spare parts	349,672	Unexpected extension of periodic maintance periods	347,203
Change of law and regulations.	299,518	Delay in procurement of equipment	235,933
Wrong capacity calculation	114,14	Fire	99,31
Wrong turbine design	79,314	Electric Shock	76,234
Wrong technology selection	68,49	Structure failures.	122,68
Health problems	159,312	Rotor blades failures	109,468
Inefficiently working	144,376	Mechanical Brake failures.	165,402
Electrical failures.	344,656	Drive train failures.	233,844
Strike of lightning	344,656	Generator failures.	191,74
Injury of 3rd person	119,926	Gearbox failures.	264,088
Devastate	115,486	Yaw system failures.	260,812
Broken of equipment	91,918	Sensor failures.	332,48
Waste time	79,548	Hydraulic system failures.	265,044
Environmental pollution	6,437	Electrical system failures.	293,4
Environmental pollution	10,918	Control system failures.	215,924
Health problems	75,808	Hub failures.	184,244
Health problems	51,536	Safety blade numbers.	69,266

3.2.5 Computing DEA with SFMEA

The DEA approach is used to determine which failure mode's response is the most effective. To improve its dependability, the FMEA approach was updated and coupled with DEA. The effectiveness of the FMEA was calculated just based on incidence, severity, and detection; in other studies, cost and/or time were taken into account in various ways.

According to the computed RPN, we were able to rate the FMs using the FMEA method. Performing a single failure mode with the highest RPN value may be less effective in some situations than performing a series of FMs with a total of RPN larger than the one on the highest RPN, with the least cost and time. When efficiency is taken into account, the question that which failure mechanisms should be minimized first. One of the suggested solutions is the combination of time and cost conceptions; that is, time and cost in order to reduce the RPN while also taking into consideration the incidence, severity, and detection. To accomplish so, a DEA model that minimizes time, cost, O, S, and D will be considered, and the RPN will be reduced. Performing an FM, is from the other hand, is effective if it has a sufficient RPN and takes minimum time and money.

To put it another way, the greater the RPN, greater effective the remedial activities will be. The RPN is an input, and cost and time are outputs, because the inputs are that we're on hand for this study and the output data are what we'll get in future work. The FMEA methodology was merged with the DEA method in this study, and several of its usage, such as SOD efficiencies, exponential RPN, and multi criteria decision making theory, were investigated. The DEA approach is used to determine which FM’s response is the most effective.

When the effectiveness value increases the outputs while decreasing the inputs, time, cost, and RPN are all taken into account in this work. Furthermore, the goal of this research is to reduce the RPN once corrective steps have been implemented, which translates to a reduction in the occurrence, severity, and detection which we have on hand, therefore O, S, and D should be regarded inputs. Finally, our inputs will be O, S, D, and the equivalent RPN; our outputs will be the opposite of cost and time; and our DMUs will be the FMs and sub-failure modes. The DMU, inputs and outputs are illustrated in below Figure.

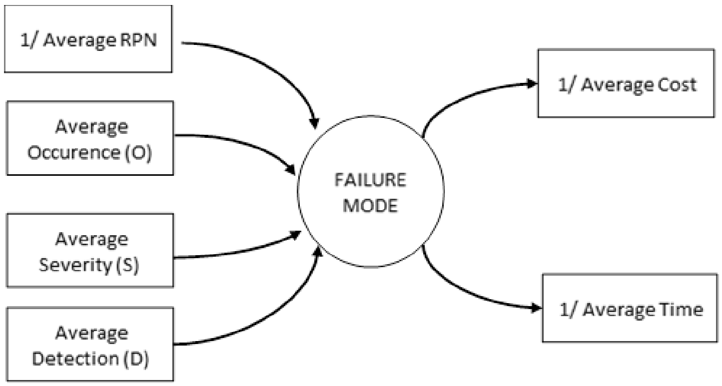

Figure 4: DEA inputs and outputs model

It is preferable to employ multi-expert views as an independently source in order to acquire far more dependable results as an output like any risk assessment methodologies. In the actual world, however, each expert carries a varied amount of weight depending on his or her personal backgrounds, such as work duration, education, experience, and, of course, a paradigm shift. (S.Shoar et al., 2017) As a result, as previously noted, a diverse group of experts has a significant advantage in terms of accuracy over a homogeneous group. (Yazdi et al., 2017) For weighing experts recruited in a diverse way, a conventional technique is used at this work. (Yazdi et al., 2018).

Table 21: Computing 1/RPN and rank value of FMs

Failures	RPN	1/RPN	Rank	Failures	RPN	1/RPN	Rank
Transportation problem	75,135	0,0133	55	Health problems	127,574	0,0078	35
Insufficient wind power (Powerless wind)	206,354	0,0048	19	Waste time	119,408	0,0084	38
Bird deaths	103,426	0,0097	44	Dangerous situation	153,648	0,0065	30
Diminishing of cultivatable areas	28,8	0,0347	60	Fall from high	83,618	0,012	50
Terorism	109,436	0,0091	43	Difficulties of emergency evacuation	48,244	0,0207	59
Civil unrest and war	187,972	0,0053	23	Electrical Shock	85,7	0,0117	49
Disagreable turbine selection	118,858	0,0084	39	Fall of material during lifting	177,202	0,0056	25
Suboptimal sitting of wind turbine into the wind farm	163,718	0,0061	28	Moving materials crash	127,968	0,0078	34
Difficulties of emergency evacuation.	100,354	0,01	45	Manuel handling	86,84	0,0115	48
Calculating mistake of investment costs	271,54	0,0037	12	Rollever of carrier vehicle	190,732	0,0052	21
Foreign exchange risk	358,362	0,0028	1	Rollever of shipment	141,248	0,0071	33
Credit risk	176,692	0,0057	26	Driver borne problems	190,48	0,0052	22
Inflation risk	355,676	0,0028	2	Operator borne problems	152,778	0,0065	31
Electricity price risk	320,6	0,0031	8	Unexpected maintenance and repair	294,968	0,0034	10
Expensive spare parts	349,672	0,0029	3	Unexpected extension of periodic maintance periods	347,203	0,0029	4
Change of law and regulations.	299,518	0,0033	9	Delay in procurement of equipment	235,933	0,0042	16

Table 21: Cont.

Failures	RPN	1/RPN	Rank	Failures	RPN	1/RPN	Rank
Wrong capacity calculation	114,14	0,0088	41	Fire	99,31	0,0101	46
Wrong turbine design	79,314	0,0126	52	Electric Shock	76,234	0,0131	53
Wrong technology selection	68,49	0,0146	57	Structure failures.	122,68	0,0082	36
Health problems	159,312	0,0063	29	Rotor blades failures	109,468	0,0091	42
Inefficiently working	144,376	0,0069	32	Mechanical Brake failures.	165,402	0,006	27
Electrical failures.	344,656	0,0029	5	Drive train failures.	233,844	0,0043	17
Strike of lightning	344,656	0,0029	5	Generator failures.	191,74	0,0052	20
Injury of 3rd person	119,926	0,0083	37	Gearbox failures.	264,088	0,0038	14
Devastate	115,486	0,0087	40	Yaw system failures.	260,812	0,0038	15
Broken of equipment	91,918	0,0109	47	Sensor failures.	332,48	0,003	7
Waste time	79,548	0,0126	51	Hydraulic system failures.	265,044	0,0038	13
Environmental pollution	6,437	0,1554	62	Electrical system failures.	293,4	0,0034	11
Environmental pollution	10,918	0,0916	61	Control system failures.	215,924	0,0046	18
Health problems	75,808	0,0132	54	Hub failures.	184,244	0,0054	24
Health problems	51,536	0,0194	58	Safety blade numbers.	69,266	0,0144	56

3.2.6 Computing Cost and Time of the reducing each of the failure's RPN value

In this study, FMEA of WF is done based on the most frequent failures. The FMs are listed in FMEA table and cause of failure effects are clarified each of failures. Experts expressed the Occurrence (O), Severity (S) and Detection (D) of each failure and$RPN = O\ X\ S\ X\ D$ numbers are calculated according to the expert's ranking. In this case we used 1/RPN and RANK value in our model. Detection methods of each failure are explained detail and solution recommended to reduce the RPN is given for each failure with approximate cost and time needed to apply the solution. The cost and time is estimated according to literature reviews and expert's opinions. Each of the failure's cost is calculated as Euro because most of the spare parts and prices of each item which are related to Wind turbine industry is frequently priced based on Euro currency. In this case we calculated costs in Euro. The ratio between TL and Euro was based on as 1 Euro is equal to 10 times of TL for our all costs.

Each failure modes and each DMU's are known as listed table.

Table 22: List of each failure modes and DMUs

FAILURES	**DMUS**	**Cause of failure**
Failure 1	DMU1	Transportation problem
Failure 2	DMU2	Insufficient WP (Powerless wind)
Failure 3	DMU3	Bird deaths
Failure 4	DMU4	Diminishing of cultivatable areas
Failure 5	DMU5	Terrorism
Failure 6	DMU6	Civil unrest and war
Failure 7	DMU7	Disagreeable turbine selection
Failure 8	DMU8	Suboptimal sitting of wind turbine into the wind farm
Failure 9	DMU9	Difficulties of emergency evacuation.
Failure 10	DMU10	Calculating mistake of investment costs
Failure 11	DMU11	Foreign exchange risk
Failure 12	DMU12	Credit risk
Failure 13	DMU13	Inflation risk
Failure 14	DMU14	Electricity price risk
Failure 15	DMU15	Expensive spare parts
Failure 16	DMU16	Change of law and regulations.
Failure 17	DMU17	Wrong capacity calculation
Failure 18	DMU18	Wrong turbine design
Failure 19	DMU19	Wrong technology selection
Failure 20	DMU20	Health problems
Failure 21	DMU21	Inefficiently working
Failure 22	DMU22	Electrical failures.

Table 22: Cont.

FAILURES	DMUS	Cause of failure
Failure 23	DMU23	Strike of lightning
Failure 24	DMU24	Injury of 3rd person
Failure 25	DMU25	Devastate
Failure 26	DMU26	Broken of equipment
Failure 27	DMU27	Waste time
Failure 28	DMU28	Environmental pollution
Failure 29	DMU29	Environmental pollution
Failure 30	DMU30	Health problems
Failure 31	DMU31	Health problems
Failure 32	DMU32	Health problems
Failure 33	DMU33	Waste time
Failure 34	DMU34	Dangerous situation
Failure 35	DMU35	Fall from high
Failure 36	DMU36	Difficulties of emergency evacuation
Failure 37	DMU37	Electrical Shock
Failure 38	DMU38	Fall of material during lifting
Failure 39	DMU39	Moving materials crash
Failure 40	DMU40	Manuel handling
Failure 41	DMU41	Rollover of carrier vehicle
Failure 42	DMU42	Rollover of shipment
Failure 43	DMU43	Driver borne problems
Failure 44	DMU44	Operator borne problems
Failure 45	DMU45	Unexpected maintenance and repair
Failure 46	DMU46	Unexpected extension of periodic maintance periods
Failure 47	DMU47	Delay in procurement of equipment
Failure 48	DMU48	Fire
Failure 49	DMU49	Electric Shock
Failure 50	DMU50	Structure failures.
Failure 51	DMU51	Rotor blades failures
Failure 52	DMU52	Mechanical Brake failures.
Failure 53	DMU53	Drive train failures.
Failure 54	DMU54	Generator failures.
Failure 55	DMU55	Gearbox failures.
Failure 56	DMU56	Yaw system failures.
Failure 57	DMU57	Sensor failures.
Failure 58	DMU58	Hydraulic system failures.
Failure 59	DMU59	Electrical system failures.
Failure 60	DMU60	Control system failures.
Failure 61	DMU61	Hub failures.
Failure 62	DMU62	Safety blade numbers.

Failure 1: Transportation problem is a cause of choosing an inappropriate wind farm area failure and effects waste time and energy. The detection method of this failure is generating access route assessment during feasibility study. Solution recommended to reduce the RPN can be possible with early detection to choose the right routes and, if necessary, shortcut road construction. According to the calculations the approximate cost of the solution is that 1 ton asphalt is approximately 350 TL.1 ton of asphalt covers an area of 26 square meters with a thickness of 15 cm. For 30 km length and 2 m wide road with 15 cm thickness around 9.000 m3 asphalt is required. If 1 ton of asphalt covers an area of 26m2, 2,307.69 tons of asphalt is required for 30,000*2 = 60,000m2. Approximately cost 808,000 TL / 81,000€. The approximate time needed to apply the solution is also stated as 60 days.

Failure 2: Insufficient WP (Powerless wind) is a cause of choosing an inappropriate wind farm area's failure and effects capacity and profit. Wind measurement should be made at the right height in accordance with international standards for detection of this failure. Solution recommended to reduce the RPN can be possible with making wind measurements during the feasibility study and start the project if the measurement results are sufficient. Minimum 1-year measurements are necessary. According to the calculations, the approximate cost of the solution is that wind measurement is required for 1 year with the installation of a wind measurement pole. Wind measurement pole - 40 mt - Cage Type: 120.000 TL (10.950 USD + VAT). The cost of the pole is 120.000 TL, if we consider 40% of the cost of the installation, the cost of construction and a staff for its follow-up: 120.000*140/100+5000*12 (Salary. The approximately cost is 230.000 TL / 22.000 €. The approximate time needed to apply the solution is also stated as 365 days.

Failure 3: Bird deaths are a cause of choosing an inappropriate wind farm area failure and effects environment. The detection method of this failure is monitoring/research of birds and bats during R&D, construction process and facility operation. In addition, to be in transparent communication with the local people help for detection. Solution recommended to reduce the RPN can be possible with making changes in the layout or applying restrictions with early detection. According to the calculations the approximate cost of the solution is that penalties for bird deaths can range from €50,000 to €500,000 depending on the country. Considering the 3.000 TL salary and insurance of 1 personnel, the cost was taken into consideration as 5000 TL. If we consider the cost of the survey and monitoring process as the annual salary of a person who will analyze the process; 12 * 5000 TL = 60.000 TL. / 6,000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 4: Diminishing of cultivatable areas is a cause of choosing an inappropriate wind farm area failure and effects environment. The detection method of this failure is obtaining opinions from the ministry of agriculture and forestry and local people. Solution recommended to reduce the RPN can be possible resettlement plan according to good relations with farmers, transparent communication, and feasibility studies. According to the calculations, the approximate cost of the solution is that it may vary by country and region, but there is no extra cost. Considering the duration of legal permits and comprehensive feasibility studies, a 1-year period can be taken into account. Permits and other research approximate cost is 5000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 5: Terrorism is a cause of choosing an inappropriate wind farm area's failure and effects profit and cost. The detection method of this failure is Consultation with local authorities. Solution recommended to reduce the RPN can be possible with Ensuring security with soldiers, police and guards. According to the calculations, the approximate cost of the solution is that it may vary by country and region, but there is no extra cost. Considering the duration of legal permits and comprehensive feasibility studies, a 1-year period can be taken into account. Permits and other research approximate cost is 5000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 6: Disagreeable turbine selection is a cause of choosing an inappropriate wind farm area’s failure and effects profit and cost. The detection method of this failure is consultation with local authorities and local people. Solution recommended to reduce the RPN can be possible with to ensure good relations with the local people, transparent communication, and transparent monitoring of the activities. According to the calculations, the approximate cost of the solution is that it may vary by country and region, but there is no extra cost. Considering the duration of legal permits and comprehensive feasibility studies, a 1-year period can be taken into account. Permits and other research approximate cost is 5000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 7: Civil unrest and war is a cause of choosing an inappropriate wind turbine failure and effects capacity and profit. The detection method of this failure is selection of turbines with the appropriate technical specifications with the site evaluation report and technical analysis of the wind regime. Solution recommended to reduce the RPN can be possible with making the selection of a turbine by calculating the capacity factors according to the wind characteristics of the field, by consulting the experts on the site evaluation report and the selection of turbines with suitable characteristics. According to the calculations, the approximate cost of the solution is that calculation of capacity factors (according to the calculation that it is measured with 4 anemometers, if we consider that an engineer analyzes the measurements on 2 different wind masts; 120.000*140/100*(2 pcs) + 850*4(4 pcs anemometers) + 5000*12 (annual) for pole installation salary) = 400.000TL / 40.000€. CF value is calculated as the ratio of the electrical energy that can be produced in a year with the current wind values from the turbine to be installed, to the energy that will be produced at full power of the turbine. The approximate time needed to apply the solution is also stated as 365 days.

Failure 8: Suboptimal sitting of wind turbine into the wind farm is a cause of wind turbine sitting mistake failure and effects capacity and profit. The detection method of this failure is CFD wind modeling and production simulation software are used for proper turbine placement (Micro sitting). During the wind measurements and feasibility studies of the field for 1 year, the wind map is drawn. The appropriate settlement plan is determined by micro sitting. Solution recommended to reduce the RPN can be possible with determination of micro sitting-layout plan. According to the calculations, the approximate cost of the solution is that the cost of implementing the micro sitting layout plan is approximately 200,000 TL / 20.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 9: Suboptimal sitting of wind turbine into the wind farm is a cause of difficulties of emergency evacuation failure and effects health. The detection method of this failure is establishing an emergency and evacuation plan. Solution recommended to reduce the RPN can be possible with establishing an emergency and evacuation plan and identifying possible problems with drills. Also training of employees is a solution for reducing RPN. According to the calculations, the approximate cost of the solution is that On-the-job training to be given to the employees and the risk assessment map to be determined by the OHS expert, and exercises are carried out at certain intervals. Reporting nonconformities as a result of observations and taking corrective and preventive actions. (1 OHS specialist can do it with a salary of approximately 8000 TL.) / 9600€ (annual). The approximate time needed to apply the solution is also stated as 365 days.

Failure 10: Unexpected investment cost is a cause of calculating mistake of investment costs failure and effects cost. The detection method of this failure is receiving a price quote on CAPEX/OPEX during the feasibility study. Workings with experienced team plays have an important role. Capex means the capital Expenditure and opex means operational expenditure. Solution recommended to reduce the RPN can be possible with All cost items to be taken into account during the feasibility study should be calculated in detail with the team to be composed of experts in the field. According to the calculations, the approximate cost of the solution is that monte carlo simulation, planning and project management costs are approximately 30.000€s. The approximate time needed to apply the solution is also stated as 365 days.

Failure 11: Unexpected investment cost is a cause of foreign exchange risk failure and effects cost. The detection method of this failure is economic and political risk assessments. Solution recommended to reduce the RPN can be possible with minimizing the losses that will arise from the exchange rate difference by taxiing the receivables in foreign currency when the exchange rate is high and making the payments in foreign currency when the exchange rate decreases. According to the calculations, the approximate cost of the solution is that finance specialist and his team. The approximate cost is 360.000 TL per year / 36.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 12: Unexpected investment cost is a cause of credit risk failure and effects cost. The detection method of this failure is economic and political risk assessments. Solution recommended to reduce the RPN can be possible with examining loan and interest rates, getting a loan in TL, Providing the necessary conditions for receiving appropriate incentives, borrowing prevention. According to the calculations, the approximate cost of the solution is that Finance Specialist and his team. The approximate cost is 360.000 TL per year / 36.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 13: Unexpected investment cost is a cause of inflation risk failure and effects cost. The detection method of this failure is Economic and political risk assessments. Solution recommended to reduce the RPN can be possible with estimated of inflation rate. According to the calculations, the approximate cost of the solution is that Finance Specialist and his team. The approximate cost is 360.000 TL per year / 36.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 14: Unexpected investment cost is a cause of electricity price risk's failure and effects cost. The detection method of this failure is determination of energy market regulatory authority (EPDK). The increase in the electricity fee is an advantageous situation for the WPP investors son o need to reduce RPN for this failure but of course when the sale price increase this can have a negative effect to energy sector so always safe sale prices are preferred to be balance. Solution recommended to reduce the RPN can be possible with estimated sales prices. According to the calculations, the approximate cost of the solution is that Finance Specialist and his team. Approximate cost is 360.000 TL per year / 36.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 15: Unexpected investment cost is a cause of expensive spare parts failure and effects cost. The detection method of this failure is researching of price. Solution recommended to reduce the RPN can be possible with Researching of price, prefer local productions, and determining the safety stock for parts that are used continuously. According to the calculations, the approximate cost of the solution is that since domestic productions are in TL and there will be no transportation and customs costs, they will be discounted at the rate of 20% per piece. If we consider that the annual maintenance cost is 300.000 € than benefit of us will be 60.000€; 60.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 16: Unexpected investment cost is a cause of change of law and regulations failure and effects management. The detection method of this failure is following of the laws and regulations regularly. Solution recommended to reduce the RPN can be possible with following the changes in the laws and laws related to the activity; to implement the actions to be taken during the activity or the revisions to be made within the legal time limit. According to the calculations, the approximate cost of the solution is that It may vary by country and region, but there is no extra cost. Permits and other research approximate cost are 5000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 17: Wrong capacity calculation is a cause of technical and engineering design mistakes failure and effects capacity and cost. The detection method of this failure is calculation of capacity. Solution recommended to reduce the RPN can be possible with capacity calculation should be done during the feasibility study with the team that will be composed of experts in the field. According to the calculations, the approximate cost of the solution is that calculation of capacity factors. According to the calculation, that it is measured with 4 anemometers, if we consider that an engineer analyzes the measurements on 2 different wind masts; 120.000*140/100* (2 pcs) + 850*4 (4 pcs anemometers) + 5000*12 (annual) for pole installation salary) = 400.000 TL / 40.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 18: Wrong turbine design is a cause of technical and engineering design mistakes failure and effects capacity and cost. The detection method of this failure is feasibility studies. Solution recommended to reduce the RPN can be possible with making the capacity planning of the facility to be established within the scope of feasibility studies and choosing the optimum turbine that will meet the need for the facility. Making the most appropriate placement is possible with we can achieve maximum efficiency. According to the calculations, the approximate cost of the solution is that turbine design belongs to the supplier company. At this point, only the cost of providing the most appropriate placement in order to achieve maximum efficiency. The cost of implementing the micro-sitting layout plan is approximately 200,000 TL / 20.000€. The approximate time needed to apply the solution is also stated as 90 days.

Failure 19: Wrong technology selection is a cause of advancement of alternative technologies may render other energy sources more feasible failure and effects capacity and cost. Selection of the most suitable energy source for the region and the size of the facility during the feasibility study is the detection method of this failure. Solution recommended to reduce the RPN can be possible with making observations and analyzes before starting the project, exchange of information from local people, exchange of information with local authorities. According to the calculations, the approximate cost of the solution is that Project's analysis cost 45.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 20: Health problems are a cause of working non-ergonomic conditions failure and effects health. The detection method of this failure is ergonomics studies that can be applied to increase productivity. Solution recommended to reduce the RPN can be possible with evaluating suggestions and requests regarding the work that can be applied according to the nature of the work to be done in terms of ergonomics, evaluation if there is a situation to be developed within the scope of productivity increase and improvement projects and organizing activities in 5S/Kaizen and lean philosophy. According to the calculations, the approximate cost of the solution is that risks that may occur in terms of health can be followed up with on-the-job training to be given to the employees and the risk assessment analysis to be determined by the OHS specialist. In addition, it is very valuable for the business manager to support productivity and innovation projects for efficiency. It is equal to the annual cost of the OHS specialist. Approximately cost is 9600€ (annual). The approximate time needed to apply the solution is also stated as 365 days.

Failure 21: Inefficiently working is a cause of working in confined spaces failure and effects health and cost. The detection method of this failure is ergonomics studies that can be applied to increase productivity. Solution recommended to reduce the RPN can be possible with evaluating suggestions and requests regarding the work that can be applied according to the nature of the work to be done in terms of ergonomics, Evaluation if there is a situation to be developed within the scope of productivity increase and improvement projects and Organizing activities in 5S/Kaizen and lean philosophy. According to the calculations, the approximate cost of the solution is that Risks that may occur in terms of health can be followed up with on-the-job training to be given to the employees and the risk assessment analysis to be determined by the OHS specialist. In addition, it is very valuable for the business manager to support productivity and innovation projects for efficiency. It is equal to the annual cost of the OHS specialist. Approximately cost is 9600€ (annual). The approximate time needed to apply the solution is also stated as 365 days.

Failure 22: Electrical failure is a cause of fire risk failure and effects cost. The detection method of this failure is technical controls. Solution recommended to reduce the RPN can be possible with be detected without downtime with planned maintenance and controls. According to the calculations, the approximate cost of the solution is that annual periodic operating and maintenance cost is approximately 8.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 23: Strike of lightning is a cause of fire risk failure and effects cost. The detection method of this failure is Lightning detection systems and Lightning Rod. It is a big problem in the industry as insurance companies do not cover lightning strikes and turbine suppliers do not take enough responsibility. Solution recommended to reduce the RPN can be possible with Contractual agreements must be made. Also the lightning detection systems, alarms, lightning rods, copper leads and strips should be used. According to the calculations, the approximate cost of the solution is that Lightning rod cost is approximately annual 7000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 24: Injury of 3rd person is a cause of icing risk failure and effects cost. The detection method of this failure is visual controls and ice detection systems. Icing causes energy production to decrease or to stop completely, turbines to get mechanically tired faster and throwing ice poses a danger to surrounding structures and living things. Solution recommended to reduce the RPN can be possible with sufficient distance from residential areas, warning signs, restriction. Also investing in anti-icing and establishment of ice detection system are necessary. According to the calculations, the approximate cost of the solution is that the ice detection system measures the amount of ice buildup on the rotor blades and ensures reliable operation for the wind turbine generator. If 1 sensor is thought to be 50€ ; the approximate cost seasonal 200€. Winter months (December-January-February-March) is considered as seasonal. The approximate time needed to apply the solution is also stated as 120 days.

Failure 25: Devastate is a cause of natural disaster failure and has a cost effect. During the project phase, opinions should be obtained from local people and disaster directorates helps to detect this failure. Solution recommended to reduce the RPN can be possible with opinions should be sought from disaster directorates. Transparent communication with local people is important. Buildings should be constructed in accordance with the permits and zoning plans received at the project stage. According to the calculations, the approximate cost of the solution is that cost of project engineering and legal permits 5000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 26: Broken of equipment is a cause of freezing of equipment's' fuels failure and effects cost. It may vary depending on weather conditions. The equipment supervisor should definitely check it. The detection method of this failure is controlled. Solution recommended to reduce the RPN can be possible with necessary training should be given to equipment supervisors and periodic controls should be provided by the equipment supervisor. Also, should use antifreeze. According to the calculations, the approximate cost of the solution is that since support will be received from the existing employees for the controls. There is no cost, but if it is considered as 1 € per liter for the antifreeze agent, the approximate cost for the consumption of 1000 liters per year. Approximated cost is 100€. The approximate time needed to apply the solution is also stated as 1 day.

Failure 27: Waste time is a cause of freezing of equipment's fuels failure and effects cost. It may vary depending on weather conditions. The equipment supervisor should definitely check it. The detection method of this failure is controls. Solution recommended to reduce the RPN can be possible with necessary training should be given to equipment supervisors and periodic controls should be provided by the equipment supervisor. According to the calculations, the approximate cost of the solution is that since support will be received from the existing employees for the controls. There is no cost, but if it is considered as 1 € per liter for the antifreeze agent, the approximate cost for the consumption of 1000 liters per year. Approximated cost is 100€. The approximate time needed to apply the solution is also stated as 1 day.

Failure 28: Environmental pollution is a cause of gas emission failure and effects environment. Thanks to periodic controls, it can be detected by gas leakage measurement method detects this failure. Solution recommended to reduce the RPN can be possible with necessary training should be given to field supervisors and periodic controls should be provided in areas that may cause gas leakage. Also, gas sensor's installation at critical points is necessary. According to the calculations, the approximate cost of the solution is that there is no cost as support will be received from existing employees for the controls. But for gas meter and sensor cost per year 1000€. The approximate time needed to apply the solution is also stated as 1 day.

Failure 29: Environmental pollution is a cause of geothermal waste risk failure and effects environment. Obtaining the permits of an activity in accordance with the procedure by the ministry of environment during the feasibility phase of the project detects this failure. Solution recommended to reduce the RPN can be possible with It is known by the literature studies and relevant authorities that there is no risk. According to the calculations, the approximate cost of the solution is that it may vary by country and region, but there is no extra cost. Permits and other research approximate cost is 5000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 30: Health problems are a cause of noise risk failure and effects environment. The detection method of this failure is measurements of decibel with using dosimeters. Solution recommended to reduce the RPN can be possible with mechanical and aerodynamic noises occur. With planned maintenance for mechanical noise, malfunctions that may cause noise in the mechanical parts can be prevented. According to the calculations, the approximate cost of the solution is that the approximate cost of periodic maintenance and turbine equipment replacement in new technology 10.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 31: Health problems are a cause of harming of 3rd parties' failure and effects health. The detection method of this failure is using PPE with warning signs and safety controls. Solution recommended to reduce the RPN can be possible with On-the-job training should be provided, personal protection and equipment should be used and field inspections by the OHS expert should be increased. According to the calculations, the approximate cost of the solution is that On-the-job training, the use of PPE with warning signs and safety controls is approximate cost is 1000€. The approximate time needed to apply the solution is also stated as 1 day.

Failure 32: Health problems are a cause of work accidents because of weather conditions failure and effects health and cost. In maintenance activities that continue throughout the year, extremely hot and cold weather conditions can lead to occupational accidents, especially during working at height detects this failure. Solution recommended to reduce the RPN can be possible with limitation of operating conditions (high wind speed definition, etc.). Parachute type seat belt: 40 €. Helmet: 20 €. Work gloves and work clothes: 60 €. 120 € per person, and if we foresee that there is a team of 25 people in the field, we can consider it as approximately cost. According to the calculations, the approximate cost of the solution is that On-the-job training, the use of PPE with warning signs and safety controls is approximate 3.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 33: Waste time is a cause of work accidents because of weather conditions failure and effects cost. In maintenance activities that continue throughout the year, extremely hot and cold weather conditions can lead to occupational accidents, especially during working at height detects this failure. Solution recommended to reduce the RPN can be possible with limitation of operating conditions (high wind speed definition, etc.). Parachute type seat belt: 40 €. Helmet: 20 €. Work gloves and work clothes: 60 €, 120 € per person, and if we foresee that there is a team of 25 people in the field, we can consider it as approximately cost. According to the calculations, the approximate cost of the solution is that On-the-job training, the use of PPE with warning signs and safety controls is approximate 3.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 34: Dangerous situation is a cause of emergency evacuation for workers failure and effects health. The detection method of this failure is establishing an emergency and evacuation plan. Solution recommended to reduce the RPN can be possible with establishing an emergency and evacuation plan and identifying possible problems with drills. And providing training to employees. On-the-job trainings to be given to the employees and the risk assessment map to be determined by the OHS expert, exercises are carried out at certain periods; Reporting nonconformities as a result of observations and taking corrective and preventive actions. The monthly salary load of the OHS Specialist was calculated as 8,000 TL. According to the calculations, the approximate cost of the solution is that can be considered as 96,000 TL per year as 9.600€ (annual). The approximate time needed to apply the solution is also stated as 365 days.

Failure 35: Fall from high is a cause of accident failure and effects health. The detection method of this failure is On-the-job trainings and inspections of OHS experts should prevent problems in practice. Solution recommended to reduce the RPN can be possible with On-the-job training should be provided. Personal protection and equipment should be used. And Field inspections by the OHS expert should be increased. Parachute type seat belt: 40 €, helmet: 20 €, work gloves and work clothes: 60 €, 120 € per person, and if we foresee that there is a team of 25 people in the field, we can consider it as approximately cost. According to the calculations, the approximate cost of the solution is that preventing accidents with the use of personal protective equipment and on-the-job training cost is 3.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 36: Difficulties of emergency evacuation is a cause of accident failure and effects health. The detection method of this failure is establishing an emergency and evacuation plan. Solution recommended to reduce the RPN can be possible with establishing an emergency and evacuation plan and identifying possible problems with drills. And providing training to employees. On-the-job trainings to be given to the employees and the risk assessment map to be determined by the OHS expert, exercises are carried out at certain periods; Reporting nonconformities as a result of observations and taking corrective and preventive actions. The monthly salary load of the OHS Specialist was calculated as 8,000 TL. According to the calculations, the approximate cost of the solution is that can be considered as 96,000 TL per year as 9.600€ (annual). The approximate time needed to apply the solution is also stated as 365 days.

Failure 37: Electrical shock is a cause of accident failure and effects health. The detection method of this failure is technician control. Solution recommended to reduce the RPN can be possible within periodic maintenance. According to the calculations, the approximate cost of the solution is that Electrical system failure 8.000€. The approximate time needed to apply the solution is also stated as 3 days.

Failure 38: Fall of material during lifting is a cause of accident failure and effects health. The detection method of this failure is creating a transportation instructions. Solution recommended to reduce the RPN can be possible with On-the-job training to be given to the employees. The risks that may occur during the transportation of the material are analyzed and appropriate transportation instructions are created. According to the calculations, the approximate cost of the solution is that The OHS expert creates On-the-job trainings and a risk assessment map. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the OHS specialist. Approximate cost is 9.600€ (annual). The approximate time needed to apply the solution is also stated as 365 days.

Failure 39: Moving materials crash is a cause of accident failure and effects cost. The detection method of this failure is creating a transportation instruction. Solution recommended to reduce the RPN can be possible with On-the-job trainings to be given to the employees. The risks that may occur during the transportation of the material are analyzed and appropriate transportation instructions are created. According to the calculations, the approximate cost of the solution is that The OHS expert creates On-the-job trainings and a risk assessment map. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the OHS specialist. The annually cost is calculated as 9.600€ (annual). The approximate time needed to apply the solution is also stated as 365 days.

Failure 40: Manuel handling is a cause of accident failure and effects health. The detection method of this failure is creating a transportation instructions. Solution recommended to reduce the RPN can be possible with On-the-job trainings to be given to the employees. The risks that may occur during the transportation of the material are analyzed and appropriate transportation instructions are created. According to the calculations, the approximate cost of the solution is that The OHS expert creates On-the-job trainings and a risk assessment map. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the OHS specialist. The annually cost is calculated as 9.600€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 41: Rollover of carrier vehicle is a cause of accident failure and effects cost. The detection method of this failure is creating a transportation instruction. Solution recommended to reduce the RPN can be possible with On-the-job trainings to be given to the employees. The risks that may occur during the transportation of the material are analyzed and appropriate transportation instructions are created. According to the calculations, the approximate cost of the solution is that The OHS expert creates On-the-job trainings and a risk assessment map. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the OHS specialist. The annually cost is calculated as 9.600€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 42: Rollover of shipment is a cause of accident failure and effects cost. The detection method of this failure is creating a load carrying instructions. Solution recommended to reduce the RPN can be possible with On-the-job trainings to be given to the employees. The risks that may occur during the load carrying of the material are analyzed and appropriate load carrying instructions are created. According to the calculations, the approximate cost of the solution is that the OHS expert creates On-the-job trainings and a risk assessment map. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the OHS specialist. The annually cost is calculated as 9.600€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 43: Driver borne problems is a cause of accident failure and effects health. The detection method of this failure is rules to be followed while driving. Solution recommended to reduce the RPN can be possible with by doing on-the-job trainings and risk analysis that may occur; the rules to be followed while driving are determined. According to the calculations, the approximate cost of the solution is that On-the-job trainings and a risk assessment map are created by the OHS expert. Its approximate cost is as much as the annual cost of the OHS specialist. The annually cost is calculated as 9.600€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 44: Operator borne problems is a cause of accident failure and effects health. The detection method of this failure is On-the-job training of the operator and instructions that the operator must follow. Solution recommended to reduce the RPN can be possible with On-the-job training and analyses of the risks that may occur are made. The rules that the operator must comply with are determined during the work. According to the calculations, the approximate cost of the solution is that The OHS expert creates On-the-job trainings and a risk assessment map. Its approximate cost is as much as the annual cost of the OHS specialist. The annually cost is calculated as 9.600€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 45: Unexpected maintenance and repair is a cause of repair/maintenance failure and effects cost and waste time. The detection method of this failure is periodic controls and maintenance. Solution recommended to reduce the RPN can be possible within periodic controls and maintenance. According to the calculations, the approximate cost of the solution is that periodic operation and maintenance cost. Approximate cost is 5.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 46: Unexpected extension of periodic maintenance periods is a cause of repair/maintenance failure and effects cost and waste time. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with minimizing the time with planned maintenance and spare parts supply and maintaining critical safety stock of necessary parts for recurring failures. According to the calculations, the approximate cost of the solution is that periodic maintenance cost. Approximate cost is 4.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 47: Delay in procurement of equipment is a cause of repair/maintenance failure and effects cost and waste time. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with minimizing the time with planned maintenance and spare parts supply. According to the calculations, the approximate cost of the solution is that periodic operation and maintenance cost. Approximate cost is 5.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 48: Fire is a cause of repair/maintenance failure and effects cost. The detection method of this failure is technician control. Solution recommended to reduce the RPN can be possible with planned maintenance and controls. It will be detected without downtime with planned maintenance and controls. According to the calculations, the approximate cost of the solution is that annual periodic operating and maintenance cost is approximately 8.000€. The approximate time needed to apply the solution is also stated as 365 days.

Failure 49: Electric shock is a cause of repair/maintenance failure and effects cost. The detection method of this failure is technician control and periodic maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. According to the calculations, the approximate cost of the solution is that electrical system cost is approximately 8.000€. The approximate time needed to apply the solution is also stated as 3 days.

Failure 50: A Structure failure is a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of structure is around 19.000€. Failure of structure's cost can be taken %20 of structure piece. According to the calculations, the approximate cost of the solution is that structure failure’s approximately cost is 3.800€. The approximate time needed to apply the solution is also stated as 7 days.

Failure 51: Rotor blades failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of rotor blade is around 30.000€. Failure of rotor blades cost can be taken %20 of rotor blades piece. According to the calculations, the approximate cost of the solution is that rotor blade's approximately cost is 6.000€. The approximate time needed to apply the solution is also stated as 30 days.

Failure 52: Mechanical brake failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of mechanical brake is around 300€. Failure of mechanical brake's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that mechanical brake failure’s approximately cost is 60 €. The approximate time needed to apply the solution is also stated as 7 days.

Failure 53: Drive train failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of drive train is around 15.000€. Failure of drive train's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that drive train failure's cost is 3.000€. The approximate time needed to apply the solution is also stated as 8 days.

Failure 54: Generator failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of generator is around 43.800€. Failure of generator's cost can be taken %20 of piece.

According to the calculations, the approximate cost of the solution is that generator failure's cost is 8.760€. The approximate time needed to apply the solution is also stated as 9 days.

Failure 55: Gearbox failure is a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of gear box is around 15.000€. Failure of gear box's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that gear box failure's cost is 3.000€. The approximate time needed to apply the solution is also stated as 10 days.

Failure 56: Yaw system failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of yaw system is around 7.500€. Failure of yaw system's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that yaw system failure's cost is 1.500€. The approximate time needed to apply the solution is also stated as 11 days.

Failure 57: Sensor failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of sensor failure is around 800€. Failure of sensor's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that Sensor failure's cost is 1.600€. The approximate time needed to apply the solution is also stated as 1 day.

Failure 58: Hydraulic system failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of hydraulic system is around 2.400€. Failure of hydraulic system's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that hydraulic system's failure cost is 480€. The approximate time needed to apply the solution is also stated as 7 days.

Failure 59: Electrical system failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of electrical system box is around 8.000€. Failure of electrical system's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that electrical system's failure cost is 1.600€. The approximate time needed to apply the solution is also stated as 3 days.

Failure 60: Control system failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of control system is around 15.000€. Failure of control system's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that control system's failure cost is 3.000€. The approximate time needed to apply the solution is also stated as 7 days.

Failure 61: Hub failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of hub is around 12.800€. Failure of hub's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that hub's failure cost is 2.560€. The approximate time needed to apply the solution is also stated as 7 days.

Failure 62: Safety blade numbers of failures are a cause of component failure and effects cost. The detection method of this failure is planned maintenance. Solution recommended to reduce the RPN can be possible with periodic maintenance. Cost of safe blade is around 30.000€. Failure of safe blade's cost can be taken %20 of piece. According to the calculations, the approximate cost of the solution is that safe blade's failure cost is 6.000€. The approximate time needed to apply the solution is also stated as 30 days.

Chapter 4

CALCULATIONS

4.1 Calculations for Dual Efficiency and Productivity analysis of RE Alternatives of OECD Countries

This study applied the output-oriented BCC model to examine the dual efficiency of RE alternatives for selected OECD countries. Data availability of RE was the only metric used to select the evaluated countries. To ensure empirical stability of DEA models, the number of evaluated units "*n*" must satisfy the criteria: $n \geq \max\{m \times s, 3(m+s)\}$ (Cooper, W.W., et al. ,2006). Considering the one input three outputs, number of units should be greater than or equal to 12. The study evaluates sixty-seven units, therefore the model is stable, and results are reliable. PIM-DEA tool was used for the efficiency analysis. Malmquist productivity index was also applied to examine the change in efficiency between periods. The RE alternatives evaluated were bioenergy, renewable-hydro, solar energy, WE, and geothermal energy for the available OECD countries. Renewable hydro and geothermal energy were excluded for 2014 and 2016 respectively due insufficient data at those periods. This does not affect the stability of the model or reliability of the results as the PPS function remains the same. The result of the analysis has two folds. The most efficient RE alternative across the evaluated OECD countries, and the most efficient RE for an individual country. The second part of the result can infer resource availability of a particular RE alternative.

Figure 5 present the average efficiency for the evaluated RE alternatives, and Table 1 shows the individual efficiency scores. Average efficiency appears to increase for all RE alternatives across the evaluated period. Bioenergy shows 20% efficiency increase in 2016 compared to 2012. Renewable hydro show 17.5% increase while WE shows a 16% increase in efficiency, and solar energy shows 11.4% increase in 2016 compared to 2012. Reliable data for geothermal energy was available for only three countries Chile, Mexico and Turkey 2014. With an efficiency score of 77.9%, 72.8% and 86.4% respectively.

Across all RE alternatives in the evaluated period and countries, bioenergy appears to be the most efficient with an average efficiency of 99.3% in 2016, followed by renewable hydro in 2016 with an average efficiency of 96.45%. WE and solar energy has an annual average maximum efficiency of 92.98% in 2016. The continues increase in average efficiency of all RE alternatives can be attributed to the growing technological advancement over the years, however, bioenergy appears to be the most significantly improved form of RE alternative.

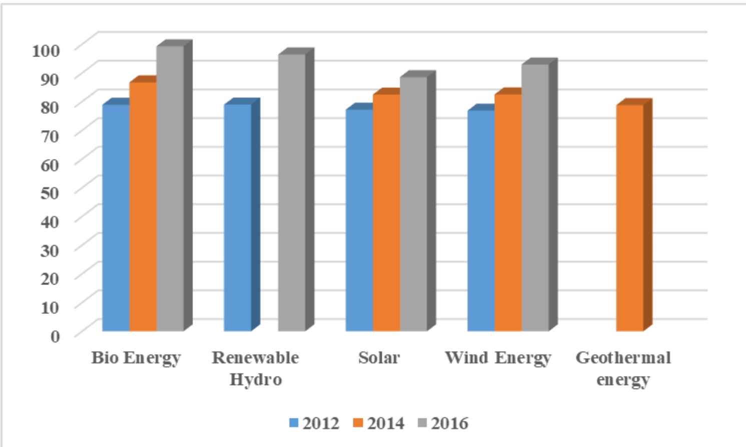

Figure 5: Average RE Dual Efficiency

Different countries at different periods appear to be the benchmark for individual RE alternative. Countries that aim to improve certain RE sources can reference the said benchmark countries. Chile and Finland 2016 are the benchmark for bioenergy, France, Italy, Turkey in 2016 are benchmark for renewable hydro, Italy in 2016 is the benchmark or solar energy, USA in 2012 and Sweden in 2016 are the benchmark for WE. For geothermal energy, reference can be made to Turkey in 2014. However, Turkey should focus more on renewable hydro as its primary source of RE. All other RE sources appear to be less efficient for Turkey. UK's WE efficiency appear to be higher than bioenergy in 2012, however, bioenergy has a higher efficiency in 2014 and 2016. Therefore, UK should focus on enhancing bio-energy systems to improve RE efficiency. Consideration can be given to RE mix of bioenergy and WE for the UK. Similarly, Sweden should focus on RE mix of bioenergy and WE. Countries can draw conclusion on which RE alternative to focus on, if they are to enhance their RE efficiency and boost their sustainable energy portfolio.

Table 23: Dual efficiency score for RE for selected OECD Countries, 2012

Energy	**Countries**	**Efficiency**	**Energy**	**Countries**	**Efficiency**
Bio Energy	Finland	71.27	Wind Energy	Austria	76.24
	Mexico	93.89		Belgium	69.82
	Spain	71.57		Denmark	70.32
	Sweden	76.16		Germany	79.8
	UK	81.77		Ireland	64.77
Renewable Hydro	Austria	79.26		Poland	72.7
	Colombia	87.43		Spain	76.07
	Denmark	70.29		UK	82.11
Solar	Chile	61.59		USA	100
	Colombia	88.53			
	Mexico	90.17			
	Spain	68.53			

Table 24: Dual efficiency score for RE for selected OECD Countries, 2014

2014					
Energy	**Countries**	**Efficiency**	**Energy**	**Countries**	**Efficiency**
Bio Energy	Chile	94.99	Solar	Mexico	100
	France	82.22		Turkey	79.48
	Italy	88.18	Wind Energy	Austria	91.08
	Mexico	81.51		Chile	77.67
	Sweden	86.34		Finland	83.72
	Turkey	84.38		Germany	93.89
	UK	89.49		Mexico	70.39
Geothermal Energy	Chile	77.9		Netherlands	86.28
	Mexico	72.08		Poland	78.47
	Turkey	86.44		Sweden	86.39
Solar	Chile	77.66		Turkey	68.95
	Israel	72.73		UK	88.5

Table 25: Dual efficiency score for RE for selected OECD Countries, 2016

2016					
Energy	**Countries**	**Efficiency**	**Energy**	**Countries**	**Efficiency**
Bio Energy	Austria	97.41	Solar	Colombia	85.5
	Chile	100		Italy	98.48
	Finland	100		Mexico	92.01
	Italy	98.59		Turkey	80.52
	Sweden	99.96	Wind Energy	Austria	95.76
	UK	99.8		Belgium	88.68
Renewable Hydro	Colombia	85.78		Netherlands	91
	France	100		Poland	93.01
	Italy	100		Sweden	100
	Turkey	100		Turkey	83.29
Solar	Chile	86,24		UK	99.05

DEA allows for weight flexibility and allocates the appropriate weights for the decision variables when calculating efficiency. The weight distribution highlights the variables that are most significant to efficiency attainment of the unit under evaluation. The average weight distribution (Capital investment= 3.67, Electricity generation from respective RE sources= 0.056, EPI=1.13, Access to clean fuels and technologies= 0.421) shows that capital investment is the most significant indicator. In the output, environmental performance and access to clean fuels and technology are significant factors for efficiency. Interestingly, all RE alternatives across the evaluated period indicate a DRS performance with the exception of Turkey's renewable-hydro energy in 2016. This discovery, together with the economic aspect being selected as one of the most important indicator, suggests that to enhance efficiency, smart economic plans regarding RE and strategic development are essential. To offer energy service, a power system mixes money and energy. (Blum, H., 2015), however, DRS is not unique in energy and electricity sector (Dhrymes, P.J and Kurz, M., 1964), mostly since they are capital intensive and require frequent maintenance to provide constant and reliable service. Therefore, countries should focus on investing in the right RE for them.

Figure 4 illustrates the average global Malmquist indices for the RE alternatives for 2012-2016, and Table 2 present the decomposition of the Global TFPC for countries with continuous data set. The TFPC is decomposed into two components, TC and EC. EC is further decomposed into SEC and PEC. Solar energy suffers from significant scale inefficiency. Renewable hydro appears to have the most improved TC in 2016 compared to 2012.

The improvement of renewable hydro is consistent across all other productivity indices. The relatively high TC for renewable-hydro and WE imply that they are the most technologically advanced RE alternative. Solar energy and Bioenergy appear to be consistent. Decomposing EC into SEC and PEC present, very interesting results. The gross scale inefficiency (SEC) of solar energy significantly impacts its productivity. The competing technical change of solar energy is as results of its technological advancement. All RE alternatives appear to have a slightly equal PEC in 2016 compared to 2012. Productivity analysis of geothermal energy could not be performed due to lack of data across other periods.

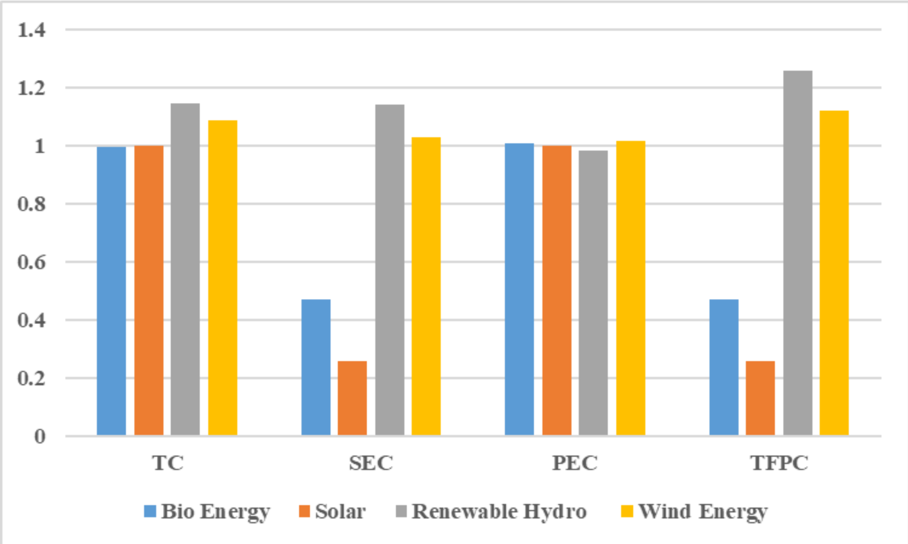

Figure 6: Average global malmquist indices (2012-2016). TC, SEC, PEC , TFPC.

Table 26: Global malmquist indices by year and country

		2012-2014			
		TC	SEC	PEC	TFPC
Bio Energy	Mexico	1	0.31	1	0.31
	Sweden	1.05	0.4	0.95	0.4
	UK	1	0.75	1	0.75
Solar	Chile	1.18	1.06	1.06	1.151
	Mexico	1	1.47	1	1.47
Wind Energy	Austria	1	0.94	1	0.94
	Germany	1	1.02	1	1.02
	Poland	1.12	1.03	0.95	1.1

Table 26: Cont.

	2014-2016				
		TC	SEC	PEC	TFPC
Bio Energy	Italy	1	0.59	1	0.59
	Sweden	1.08	2.15	1	2.31
	UK	1	1.05	1	1.05
Solar	Chile	1.15	1.15	0.96	1.29
	Mexico	1	0.2	1	0.2
	Turkey	1.05	0.03	0.89	0.03
Wind Energy	Austria	1.01	0.62	0.99	0.62
	Netherlands	1.12	1.37	0.91	1.29
	Poland	1.12	0.43	1.01	0.49
	Sweden	1.01	1.32	1.09	1.09
Wind Energy	Turkey	0.96	1.45	1.09	1.52
	UK	1	1.61	1	1.61
	2012-2016				
Bio Energy	Finland	0.99	0.16	1.02	0.16
	Sweden	1	0.59	1	0.59
Renewable Hydro	Colombia	1	0.26	1	0.26
Solar	Chile	1.21	1.56	1.11	1.25
	Colombia	1.08	0.01	0.86	0.01
Wind Energy	Austria	1.09	1.03	1	1.12
	Belgium	1.21	0.36	0.97	0.43
	Poland	0.96	1.38	1.08	1.48

Results indicate bioenergy as the most efficient RE alternative with a 20% increase in average efficiency in 2016 compared to 2012. Renewable hydro energy, WE, and solar energy show a 17.5%, 16%, and 11% increase, respectively. The average efficiency growth across all RE alternatives signifies major advancement.

4.2 An Extension of SFMEA for WT

In this study, we suggest evaluating wind turbine system technique using Smart FMEA, which is a mix of standard FMEA, DEA, and AHP. The FMEA are focus on the components of WT. It also examines the interaction among components of WFs which will be provided as downtime, cost criticalities are examined with kind of WT utilizing AHP and DEA with crisp linguistic modeling, and analyzes the impacts of decision factors with using Smart FMEA on WT.

The table of Failure Modes and Effect Analysis is explained in Chapter 3. The Calculation method of the FMEA methodology and the expert's weight is shown in table 20 at chapter 3's computation part. AHP method was used to compute each expert's capability and assigning the respective weights. In this regard, the following weights 0.47, 0.301, 0.124, 0,058 and 0,046 are given to E1, E2, E3, E4 and E5, respectively. These calculations are done, and detail explained previous chapter. At below table you can see the O, S, D scores of FMEA tables with are given by each expert.

Table 27: Calculation of FMEA table with using expert's weights

Failure modes	**Cause of failure**	**Effects**	**Occurrence (O)**	**Severity (S)**	**Detection (D)**	**RPN**
Choosing an inappropri-ate wind farm area	Transportation problem	Waste time and energy	5,981	6,707	1,775	75,135
	Insufficient wind power (Powerless wind)	Capacity and Profit	5,433	7,432	5,529	206,354
	Bird deaths	Environment	5,043	9,358	2,26	103,426
	Diminishing of cultivatable areas	Environment	2,311	7,548	2,337	28,8
	Terorism	Profit and cost	3,375	8,912	3,691	109,436
	Civil unrest and war	Cost	3,702	7,167	5,682	187,972
Choosing an inappropri-ate wind turbine	Disagreeable turbine selection	Capacity and Profit	3,022	8,918	4,183	118,858

Table 27: Cont.

Failure modes	Cause of failure	Effects	Occurrence (O)	Severity (S)	Detection (D)	RPN
Wind turbine sitting mistake	Suboptimal sitting of wind turbine into the wind farm	Capacity and Profit	5,772	9,492	2,873	163,718
	Difficulties of emergency evacuation.	Health	2,853	9,226	3,165	100,354
Unexpected investment cost	Calculating mistake of investment costs	Cost	4,559	9,446	5,318	271,54
	Foreign exchange risk	Cost	6,579	9,84	6,673	358,362
	Credit risk	Cost	3,323	8,934	5,769	176,692
	Inflation risk	Cost	8,536	7,517	5,921	355,676
	Electricity price risk	Cost	8,103	8,108	5,236	320,6
	Expensive spare parts	Cost	8,314	8,816	4,571	349,672
	Change of law and regulations.	Management	6,539	7,85	5,617	299,518
Technical and Engineering design mistakes	Wrong capacity calculation	Capacity and cost	4,296	8,61	3,075	114,14
	Wrong turbine design	Capacity and cost	2,913	7,754	3,359	79,314
Advanceme nt of alternative technologies may render other energy sources more feasible	Wrong technology selection	Capacity and cost	2,625	8,072	3,355	68,49
Working non ergonomic conditions	Health problems	Health	5,266	9,11	3,239	159,312

Table 27: Cont.

Failure modes	Cause of failure	Effects	Occurrence (O)	Severity (S)	Detection (D)	RPN
Working in confined spaces	Inefficiently working	Health and cost	7,43	6,867	2,768	144,376
Fire risk	Electrical failures.	Cost	7,42	9,428	5,073	344,656
	Strike of lightning	Cost	6,676	8,188	3,833	344,656
Icing risk	Injury of 3rd person	Health	2,547	7,594	3,927	119,926
Natural disaster	Devastate	Cost	2,501	9,428	4,445	115,486
Freezing of equipment's fuels	Broken of equipment	Cost	2,389	6,48	5,083	91,918
	Waste time	Cost	2,375	6,238	4,775	79,548
Gas emission	Environmental pollution	Environment	0,999	4,087	1,469	6,437
Geothermal waste risk	Environmental pollution	Environment	0,999	6,292	1,77	10,918
Noise	Health problems	Environment	3,695	7,938	2,121	75,808
Harming of 3rd parties	Health problems	Health	1,957	8,9	2,905	51,536
Work accidents because of weather conditions	Health problems	Cost	3,079	9,944	4,938	127,574
	Waste time	Cost	3,071	8,983	4,826	119,408
Emergency evacuation for workers	Dangerous situation	Health	2,885	9,944	5,944	153,648
Accident	Fall from high	Health	1,965	9,342	4,436	83,618
	Difficulties of emergency evacuation	Health	2,111	9,25	2,18	48,244
	Electrical Shock	Health	2,676	9,886	3,639	85,7
	Fall of material during lifting	Health	5,526	8,648	3,985	177,202

Table 27: Cont.

Failure modes	Cause of failure	Effects	Occurrence (O)	Severity (S)	Detection (D)	RPN
Accident	Moving materials crash	Cost	2,972	8,329	5,192	127,968
	Manuel handling	Health	2,419	6,133	6,414	86,84
	Rollever of carrier vehicle	Cost	3,961	8,009	6,058	190,732
	Rollever of shipment	Cost	3,016	8,055	6,058	141,248
	Driver borne problems	Health	4,1	7,453	6,155	190,48
	Operator borne problems	Health	3,44	8,055	5,659	152,778
Repair/Maintenance	Unexpected maintenance and repair	Cost and waste time	4,144	8,643	8,003	294,968
	Unexpected extension of periodic maintance periods	Cost and waste time	5,951	7,995	6,383	347,203
	Delay in procurement of equipment	Cost and waste time	4,999	8,211	5,615	235,933
	Fire	Cost	2,134	8,534	4,675	99,31
	Electric Shock	Cost	2,514	9,041	4,048	76,234
Component failure	Structure failures.	Cost	4,904	8,806	3,282	122,68
	Rotor blades failures	Cost	2,666	8,168	4,954	109,468
	Mechanical Brake failures.	Cost	2,48	9,84	6,856	165,402
	Drive train failures.	Cost	4,458	9,794	5,617	233,844
	Generator failures.	Cost	3,602	9,5	5,753	191,74

Table 27: Cont.

Failure modes	Cause of failure	Effects	Occurrence (O)	Severity (S)	Detection (D)	RPN
Component failure	Yaw system failures.	Cost	5,035	8,888	6,041	260,812
	Sensor failures.	Cost	6,811	7,77	6,293	332,48
	Hydraulic system failures.	Cost	5,104	9,69	5,667	265,044
	Electrical system failures.	Cost	4,77	9,794	6,365	293,4
	Control system failures.	Cost	4,058	9,678	5,817	215,924
	Hub failures.	Cost	3,016	9,84	6,365	184,244
	Safety blade numbers.	Cost	2,311	7,006	4,259	69,266

The recommended solution methods to reduce the RPN and the Approximate cost of the solution with the approximate time needed to apply the solution is calculated at previous chapter and the detail explanations are given for each of the failure's recommended solution. At below table you can see the weighted RPN scores and approximate cost and needed time to apply solution of FMEA tables.

Table 28: Cost and time calculation of FMEA table

Cause of failure	Effects	RPN	App. Cost	App. Time
Transportation problem	Waste time and energy	75,135	81,00 €	60 days
Insufficient WP (Powerless wind)	Capacity and Profit	206,354	22.000 €	365 days
Bird deaths	Environment	103,426	6.000 €	365 days
Diminishing of cultivatable areas	Environment	28,8	5.000 €	365 days
Terorism	Profit and cost	109,436	5.000 €	365 days

Table 28: Cont.

Cause of failure	Effects	RPN	App. Cost	App. Time
Civil unrest and war	Cost	187,972	5.000 €	365 days
Disagreeable turbine selection	Capacity and Profit	118,858	40.000 €	365 days
Suboptimal sitting of wind turbine into the wind farm	Capacity and Profit	163,718	20.000 €	365 days
Difficulties of emergency evacuation.	Health	100,354	9.600 €	365 days
Calculating mistake of investment costs	Cost	271,54	30.000 €	365 days
Foreign exchange risk	Cost	358,362	36.000 €	365 days
Credit risk	Cost	176,692	36.000 €	365 days
Inflation risk	Cost	355,676	36.000 €	365 days
Electricity price risk	Cost	320,6	0 €	365 days
Expensive spare parts	Cost	349,672	60.000 €	365 days
Change of law and regulations.	Management	299,518	5.000 €	365 days
Wrong capacity calculation	Capacity and cost	114,14	40.000 €	365 days
Wrong turbine design	Capacity and cost	79,314	20.000 €	90 days
Wrong technology selection	Capacity and cost	68,49	**45.000 €**	365 days
Health problems	Health	159,312	9.600 €	365 days
Inefficiently working	Health and cost	144,376	9.600 €	365 days
Electrical failures.	Cost	344,656	8.000 €	365 days
Strike of lightning	Cost	344,656	7.000 €	365 days
Injury of 3rd person	Health	119,926	200 €	120 days
Devastate	Cost	115,486	5.000 €	365 days
Broken of equipment	Cost	91,918	100 €	1 day
Waste time	Cost	79,548	100 €	1 day
Environmental pollution	Environment	6,437	1.000 €	1 day
Environmental pollution	Environment	10,918	5.000 €	365 days
Health problems	Environment	75,808	10.000 €	365 days
Health problems	Health	51,536	1.000 €	1 day
Health problems	Cost	127,574	3.000 €	365 days
Waste time	Cost	119,408	3.000 €	365 days
Dangerous situation	Health	153,648	9.600 €	365 days
Fall from high	Health	83,618	3.000 €	365 days
Difficulties of emergency evacuation	Health	48,244	9.600 €	365 days
Electrical Shock	Health	85,7	8.000 €	3 days
Fall of material during lifting	Health	177,202	9.600 €	365 days

Table 28: Cont.

Cause of failure	Effects	RPN	App. Cost	App. Time
Moving materials crash	Cost	127,968	9.600 €	365 days
Manuel handling	Health	86,84	9.600 €	365 days
Rollever of carrier vehicle	Cost	190,732	9.600 €	365 days
Rollever of shipment	Cost	141,248	9.600 €	365 days
Driver borne problems	Health	190,48	9.600 €	365 days
Operator borne problems	Health	152,778	9.600 €	365 days
Unexpected maintenance and repair	Cost and waste time	294,968	5.000 €	365 days
Unexpected extension of periodic maintance periods	Cost and waste time	347,203	4.000 €	365 days
Delay in procurement of equipment	Cost and waste time	235,933	5.000 €	365 days
Fire	Cost	99,31	8.000 €	365 days
Electric Shock	Cost	76,234	8.000 €	3 days
Structure failures.	Cost	122,68	3.800 €	7 days
Rotor blades failures	Cost	109,468	6.000 €	30 days
Mechanical Brake failures.	Cost	165,402	60 €	7 days
Drive train failures.	Cost	233,844	3.000 €	8 days
Generator failures.	Cost	191,74	8.760 €	9 days
Gearbox failures.	Cost	264,088	3.000 €	10 days
Yaw system failures.	Cost	260,812	1.500 €	11 days
Sensor failures.	Cost	332,48	1.600 €	1 day
Hydraulic system failures.	Cost	265,044	480 €	7 days
Electrical system failures.	Cost	293,4	1.600 €	3 days
Control system failures.	Cost	215,924	3.000 €	7 days
Hub failures.	Cost	184,244	2.560 €	7 days
Safety blade numbers.	Cost	69,266	6.000 €	30 days

The Inputs are O, S, D and 1/RPN and outputs are 1/Cost, 17 time. All of the data normalized, this means that for each one of the columns all of the entrice divided by its maximum element.

Table 29: Normalized inputs and outputs table

DMU	O	S	D	1/RPN	1/C	1/T
DMU01	0,719389	0,674477	0,221792	0,085672	0,000123	0,016667
DMU02	0,653476	0,747385	0,690866	0,031194	0,000455	0,002740
DMU03	0,606567	0,941070	0,282394	0,062238	0,001667	0,002740
DMU04	0,277965	0,759051	0,292015	0,223507	0,002000	0,002740
DMU05	0,405942	0,896219	0,461202	0,058820	0,002000	0,002740
DMU06	0,445273	0,720736	0,709984	0,034244	0,002000	0,002740
DMU07	0,363483	0,896822	0,522679	0,054157	0,000250	0,002740
DMU08	0,694251	0,954545	0,358990	0,039318	0,000500	0,002740
DMU09	0,343156	0,927796	0,395477	0,064143	0,001042	0,002740
DMU10	0,548352	0,949920	0,664501	0,023706	0,000333	0,002740
DMU11	0,791316	0,989541	0,833812	0,017962	0,000278	0,002740
DMU12	0,399687	0,898431	0,720855	0,036431	0,000278	0,002740
DMU13	1,026702	0,755933	0,739848	0,018098	0,000278	0,002740
DMU14	0,974621	0,815366	0,654255	0,020078	1,000000	0,002740
DMU15	1,000000	0,886565	0,571161	0,018409	0,000167	0,002740
DMU16	0,786505	0,789421	0,701862	0,021491	0,002000	0,002740
DMU17	0,516719	0,865849	0,384231	0,056396	0,000250	0,002740
DMU18	0,350373	0,779767	0,419718	0,081158	0,000500	0,011111
DMU19	0,315732	0,811746	0,419218	0,093984	0,000222	0,002740
DMU20	0,633389	0,916130	0,404723	0,040405	1,000000	0,002740
DMU21	0,893673	0,690567	0,345870	0,044585	1,000000	0,002740
DMU22	0,892471	0,948109	0,633887	0,018677	0,001250	0,002740
DMU23	0,802983	0,823411	0,478945	0,018677	0,001429	0,002740
DMU24	0,306351	0,763677	0,490691	0,053675	0,050000	0,008333
DMU25	0,300818	0,948109	0,555417	0,055738	0,002000	0,002740
DMU26	0,287347	0,651649	0,635137	0,070030	0,100000	1,000000
DMU27	0,285663	0,627313	0,596651	0,080920	0,100000	1,000000
DMU28	0,120159	0,411002	0,183556	1,000000	0,010000	1,000000
DMU29	0,120159	0,632743	0,221167	0,589576	0,002000	0,002740
DMU30	0,444431	0,798270	0,265026	0,084912	0,001000	0,002740
DMU31	0,235386	0,895012	0,362989	0,124903	0,010000	1,000000
DMU32	0,370339	1,000000	0,617019	0,050457	0,003333	0,002740
DMU33	0,369377	0,903359	0,603024	0,053908	0,003333	0,002740
DMU34	0,347005	1,000000	0,742721	0,041894	0,001042	0,002740
DMU35	0,236348	0,939461	0,554292	0,076981	0,003333	0,002740
DMU36	0,253909	0,930209	0,272398	0,133426	0,001042	0,002740
DMU37	0,321867	0,994167	0,454704	0,075111	0,001250	0,002740

Table 29: Cont.

DMU	O	S	D	1/RPN	1/C	1/T
DMU38	0,664662	0,869670	0,497938	0,036326	0,001042	0,002740
DMU39	0,357469	0,837591	0,648757	0,050302	0,001042	0,002740
DMU40	0,290955	0,616754	0,801449	0,074125	0,001042	0,002740
DMU41	0,476425	0,805410	0,756966	0,033749	0,001042	0,002740
DMU42	0,362762	0,810036	0,756966	0,045572	0,001042	0,002740
DMU43	0,493144	0,749497	0,769087	0,033794	0,001042	0,002740
DMU44	0,413760	0,810036	0,707110	0,042133	0,001042	0,002740
DMU45	0,498436	0,869167	1,000000	0,021823	0,002000	0,002740
DMU46	0,715781	0,804002	0,797576	0,018540	0,002500	0,002740
DMU47	0,601275	0,825724	0,701612	0,027283	0,002000	0,002740
DMU48	0,256675	0,858206	0,584156	0,064817	0,001250	0,002740
DMU49	0,302382	0,909191	0,505810	0,084437	0,001250	0,333333
DMU50	0,589848	0,885559	0,410096	0,052470	0,002632	0,142857
DMU51	0,320664	0,821400	0,619018	0,058803	0,001667	0,033333
DMU52	0,298292	0,989541	0,856679	0,038917	0,166667	0,142857
DMU53	0,536204	0,984916	0,701862	0,027527	0,003333	0,125000
DMU54	0,433245	0,955350	0,718855	0,033571	0,001143	0,111111
DMU55	0,573250	0,989541	0,717356	0,024374	0,003333	0,100000
DMU56	0,605605	0,893805	0,754842	0,024681	0,006667	0,090909
DMU57	0,819221	0,781376	0,786330	0,019361	0,006250	1,000000
DMU58	0,613904	0,974457	0,708109	0,024287	0,020833	0,142857
DMU59	0,573731	0,984916	0,795327	0,021939	0,006250	0,333333
DMU60	0,488092	0,973250	0,726852	0,029811	0,003333	0,142857
DMU61	0,362762	0,989541	0,795327	0,034937	0,003906	0,142857
DMU62	0,277965	0,704545	0,532175	0,092932	0,001667	0,033333

In this study, the Primal and dual forms of input-oriented Charnes-Cooper-Rhodes (CCR) Model and Banker, Charnes, Cooper (BCC) Model is used by PIM-DEA software. Data table is normalized by dividing the elements of each column but the largest number at the same column than in the resulted table all of data are between of 0 and 1. We combined SFMEA model and DEA for each of failure modes and an efficiency of CCR model is calculated by DEA The efficiency of CCR model is given as below table.

Table 30: Efficiency of CCR model

Name	**Efficiency**	**Name**	**Efficiency**
DMU01	2,71	DMU32	0,73
DMU02	0,33	DMU33	0,73
DMU03	0,61	DMU34	0,47
DMU04	0,63	DMU35	1,12
DMU05	0,5	DMU36	0,49
DMU06	0,59	DMU37	0,43
DMU07	0,34	DMU38	0,45
DMU08	0,51	DMU39	0,41
DMU09	0,45	DMU40	0,43
DMU10	0,39	DMU41	0,45
DMU11	0,32	DMU42	0,44
DMU12	0,37	DMU43	0,44
DMU13	0,32	DMU44	0,43
DMU14	100	DMU45	0,67
DMU15	0,38	DMU46	0,62
DMU16	0,5	DMU47	0,55
DMU17	0,41	DMU48	0,54
DMU18	1,32	DMU49	35,06
DMU19	0,31	DMU50	20,01
DMU20	100	DMU51	3,63
DMU21	100	DMU52	46
DMU22	0,45	DMU53	15,49
DMU23	0,57	DMU54	14,46
DMU24	10,81	DMU55	12,43
DMU25	0,62	DMU56	11,3
DMU26	100	DMU57	100
DMU27	100	DMU58	18,98
DMU28	100	DMU59	42,39
DMU29	1,31	DMU60	18,23
DMU30	0,5	DMU61	20,02
DMU31	100	DMU62	3,33

The Efficiency of CCR Model is ordered from More Efficiency to Low

Efficiency in Table 31.

Table 31: Efficiency of CCR model is ordered from more efficiency to low efficiency

Name	Efficiency	Name	Efficiency
DMU14	100	DMU46	0,62
DMU20	100	DMU03	0,61
DMU21	100	DMU06	0,59
DMU26	100	DMU23	0,57
DMU27	100	DMU47	0,55
DMU28	100	DMU48	0,54
DMU31	100	DMU08	0,51
DMU57	100	DMU05	0,5
DMU52	46	DMU16	0,5
DMU59	42,39	DMU30	0,5
DMU49	35,06	DMU36	0,49
DMU61	20,02	DMU34	0,47
DMU50	20,01	DMU09	0,45
DMU58	18,98	DMU22	0,45
DMU60	18,23	DMU38	0,45
DMU53	15,49	DMU41	0,45
DMU54	14,46	DMU42	0,44
DMU55	12,43	DMU43	0,44
DMU56	11,3	DMU37	0,43
DMU24	10,81	DMU40	0,43
DMU51	3,63	DMU44	0,43
DMU62	3,33	DMU17	0,41
DMU01	2,71	DMU39	0,41
DMU18	1,32	DMU10	0,39
DMU29	1,31	DMU15	0,38
DMU35	1,12	DMU12	0,37
DMU32	0,73	DMU07	0,34
DMU33	0,73	DMU02	0,33
DMU45	0,67	DMU11	0,32
DMU04	0,63	DMU13	0,32
DMU25	0,62	DMU19	0,31

As seen in the table DMU14, DMU20, DMU21, DMU 26, DMU27, DMU28, DMU31, DMU57 are efficient. Based on the inherent of DEA models, they consider more efficiency value for DMUs, which consume fewer inputs to produce more outputs. So, the above efficient DMUs are the failure modes with low occurrence severity, detection and high RPN (When RPN is increase; 1/RPN is decrease) which needs less cost and time for repairing. (When cost and time decrease; 1/cost and 1/time will increase).

When assessing efficiency, DEA provides for weight variation and assigns they might be to the decision variables. The distribution of weight indicates the factors that are more important to the unit's efficiency achievement.

Table 32 shows the weights of the inputs and outputs in evaluating of DMUs obviously highest value for each one of the weights implies on more contribution or importance of the associate input or output in the efficiency value of under evaluation DMU. The entries for last row of Table 32 contain the summation of related column. These numbers are shows that the degree of general importance of inputs and outputs in the efficiency value of DMUs. Then they identify the significant input or output which impact the efficiency values. So RPN is most significant indicator in the evaluation and severity is the worst one the second significant input is occurrence and the third one is detection. Also, both of the outputs have significant contribution and evaluation.

Table 32: Weight of the CCR model

Name	**O**	**S**	**D**	**1/RPN**	**1/C**	**1/T**
DMU01	0	0	4,2	0,86	0	1,6
DMU02	1	0	0	12,04	1,1	1
DMU03	0	0	1,9	7,56	1	1,6
DMU04	3	0	0,2	0,44	2	0,8
DMU05	0,2	0	1,3	5,27	0,9	1,2
DMU06	1,1	0	0	14,37	1,3	1,2
DMU07	0	0	1,3	5,47	0,7	1,2
DMU08	0	0	1,9	7,79	1	1,7
DMU09	0	0	1,5	6,18	0,8	1,3

Table 32: Cont.

Name	**O**	**S**	**D**	**1/RPN**	**1/C**	**1/T**
DMU10	1,2	0	0	14,88	1,4	1,3
DMU11	0	0	0	55,67	1,1	1,1
DMU12	1,2	0	0	14,68	1,3	1,2
DMU13	0	0	0	55,25	1,1	1,1
DMU14	0,4	0,6	0	4,46	1	0
DMU15	0	0	1,6	6,24	0,8	1,3
DMU16	0,9	0	0	14,63	1,1	1
DMU17	0	0	1,6	6,59	0,9	1,4
DMU18	0	0	1,3	5,41	0,7	1,2
DMU19	0	0	1,2	5,07	0,7	1,1
DMU20	0,4	0,6	0	4,46	1	0
DMU21	0,4	0,6	0	4,46	1	0
DMU22	0	0	1,2	14,48	1	1,2
DMU23	0	0	1,4	17,62	1,3	1,4
DMU24	3,2	0	0	0,38	2	0,7
DMU25	3,3	0	0	0,38	2,1	0,8
DMU26	0	0,1	1,1	3,92	0,6	0,9
DMU27	0	0,6	1	0,52	0,8	0,9
DMU28	0	0,7	0,9	0,56	0	1
DMU29	8,3	0	0	0	5,3	1
DMU30	0	0	3,5	0,73	1,3	1,4
DMU31	0	0,2	0,9	3,52	0	1
DMU32	2,7	0	0	0,31	1,7	0,6
DMU33	2,7	0	0	0,31	1,7	0,6
DMU34	1,1	0	0	14,4	1,3	1,2
DMU35	4,1	0	0	0,48	2,6	0,9
DMU36	0,6	0	2,8	0,65	1,5	1,2
DMU37	2,8	0	0,2	0,4	1,8	0,8
DMU38	0	0	1,6	6,25	0,8	1,3
DMU39	1	0	0	12,71	1,2	1,1
DMU40	3,3	0	0	0,39	2,1	0,8
DMU41	1,1	0	0	13,98	1,3	1,2
DMU42	1,1	0	0	13,45	1,2	1,1
DMU43	1,1	0	0	13,71	1,2	1,2
DMU44	1,1	0	0	13,34	1,2	1,1
DMU45	1,3	0	0	16,3	1,5	1,4
DMU46	1	0	0	16,35	1,3	1,1
DMU47	1,1	0	0	13,34	1,2	1,1
DMU48	3,8	0	0	0,45	2,4	0,9
DMU49	0,2	0	1	5,14	0	1,1
DMU50	0	0	1,6	6,48	0,8	1,4

Table 32: Cont.

Name	**O**	**S**	**D**	**1/RPN**	**1/C**	**1/T**
DMU51	1,1	0	0	11,19	0	1,1
DMU52	3,3	0	0	0,39	2,1	0,8
DMU53	1,2	0	0	12,72	0	1,2
DMU54	1,3	0	0	13,36	0	1,3
DMU55	1,1	0	0	14,32	1,3	1,2
DMU56	1,1	0	0	13,75	1,2	1,2
DMU57	0	0,2	0,9	3,52	0	1
DMU58	1,1	0	0	13,7	1,2	1,2
DMU59	1,2	0	0	13,06	0	1,3
DMU60	1,3	0	0	13,1	0	1,3
DMU61	1,4	0	0	14,39	0	1,4
DMU62	0	0,2	0,9	3,51	0	1
Total	**68,6**	**3,8**	**37,1**	**569,34**	**67,9**	**66,3**

Table 33 contains the value of λ_j is in the envelopment side of CCR model and for an inefficient DMU. Those numbers shows that this DMU in its efficiency improvement procedure can compare itself by efficient DMUs, which have a positiveλ_j . For example, for DMU58 because $\lambda_{20} = 0{,}02$, $\lambda_{26} = 0{,}02$ and $\lambda_{57} = 0{,}12$, Table 33 suggest that this DMU for increasing its efficiency performance should compare itself with DMUs like as DMU20, DMU26 and DMU57. It obvious that these adjustments should results less time and cost consumption for repairing and fixing for each in efficient FM, in its efficiency improvement procedure.

Table 33: Lambdas of the CCR model

	DMU14	DMU20	DMU21	DMU26	DMU27	DMU28	DMU31	DMU57
DMU01	0	0	0	0	0	0	0,02	0
DMU02	0	0	0	0	0	0	0	0
DMU03	0	0	0	0	0	0	0	0
DMU04	0	0	0	0	0	0	0	0
DMU05	0	0	0	0	0	0	0	0
DMU06	0	0	0	0	0	0	0	0
DMU07	0	0	0	0	0	0	0	0

Table 33: Cont.

	DMU14	DMU20	DMU21	DMU26	DMU27	DMU28	DMU31	DMU57
DMU08	0	0	0	0	0	0	0	0
DMU09	0	0	0	0	0	0	0	0
DMU10	0	0	0	0	0	0	0	0
DMU11	0	0	0	0	0	0	0	0
DMU12	0	0	0	0	0	0	0	0
DMU13	0	0	0	0	0	0	0	0
DMU14	1	0	0	0	0	0	0	0
DMU15	0	0	0	0	0	0	0	0
DMU16	0	0	0	0	0	0	0	0
DMU17	0	0	0	0	0	0	0	0
DMU18	0	0	0	0	0	0	0,01	0
DMU19	0	0	0	0	0	0	0	0
DMU20	0	1	0	0	0	0	0	0
DMU21	0	0	1	0	0	0	0	0
DMU22	0	0	0	0	0	0	0	0
DMU23	0	0	0	0	0	0	0	0
DMU24	0	0,05	0	0	0	0	0	0
DMU25	0	0	0	0	0	0	0	0
DMU26	0	0	0	1	0	0	0	0
DMU27	0	0	0	0	1	0	0	0
DMU28	0	0	0	0	0	1	0	0
DMU29	0	0	0	0	0	0	0	0
DMU30	0	0	0	0	0	0	0	0
DMU31	0	0	0	0	0	0	1	0
DMU32	0	0	0	0	0	0	0	0
DMU33	0	0	0	0	0	0	0	0
DMU34	0	0	0	0	0	0	0	0
DMU35	0	0	0	0	0	0	0	0
DMU36	0	0	0	0	0	0	0	0
DMU37	0	0	0	0	0	0	0	0
DMU38	0	0	0	0	0	0	0	0
DMU39	0	0	0	0	0	0	0	0
DMU40	0	0	0	0	0	0	0	0
DMU41	0	0	0	0	0	0	0	0
DMU42	0	0	0	0	0	0	0	0
DMU43	0	0	0	0	0	0	0	0
DMU44	0	0	0	0	0	0	0	0
DMU45	0	0	0	0	0	0	0	0

Table 33: Cont.

	DMU14	DMU20	DMU21	DMU26	DMU27	DMU28	DMU31	DMU57
DMU46	0	0	0	0	0	0	0	0
DMU47	0	0	0	0	0	0	0	0
DMU48	0	0	0	0	0	0	0	0
DMU49	0	0	0	0,16	0	0	0,14	0,03
DMU50	0	0	0	0	0	0	0,07	0,07
DMU51	0	0	0	0,03	0	0	0	0
DMU52	0	0,15	0	0	0,14	0	0	0
DMU53	0	0	0	0,04	0	0	0	0,09
DMU54	0	0	0	0,05	0	0	0	0,06
DMU55	0	0	0	0,02	0	0	0	0,08
DMU56	0	0	0	0,02	0	0	0	0,07
DMU57	0	0	0	0	0	0	0	1
DMU58	0	0,02	0	0,02	0	0	0	0,12
DMU59	0	0	0	0,06	0	0	0	0,28
DMU60	0	0	0	0,05	0	0	0	0,09
DMU61	0	0	0	0,08	0	0	0	0,06
DMU62	0	0	0	0	0,02	0	0,01	0

Also, Table 33 gives a hint to rank the efficient DMUs and complete the ranking of FMs in Table 31. When an efficient DMU referenced more than other efficient DMUs (by its positive λ_j value, it means that it is more important than other efficient DMUs in the evaluation process. Then we may have the following ranking for the under consideration FMs. Table 34 contains the ordered FMs by SFMEA and Original FMEA.

Table 34: Priority of FMs based on original FMEA and SFMEA

FMs	Cause of failure	RPN	RANK	DMUs	EFFI-CIENCY	RANK
FM11	Foreign exchange risk	358,36	1	DMU57	100	1
FM13	Inflation risk	355,68	2	DMU26	100	2
FM15	Expensive spare parts	349,67	3	DMU31	100	3
FM46	Unexpected extension of periodic maintance periods	347,2	4	DMU20	100	4

Table 34: Cont.

FMs	Cause of failure	RPN	RANK	DMUs	EFFI-CIENCY	RANK
FM22	Electrical failures.	344,66	5	DMU27	100	5
FM23	Strike of lightning	344,66	5	DMU28	100	6
FM57	Sensor failures.	332,48	7	DMU31	100	6
FM14	Electricity price risk	320,6	8	DMU14	100	6
FM16	Change of law and regulations.	299,52	9	DMU52	46	9
FM45	Unexpected maintenance and repair	294,97	10	DMU59	42,39	10
FM59	Electrical system failures.	293,4	11	DMU49	35,06	11
FM10	Calculating mistake of investment costs	271,54	12	DMU61	20,02	12
FM58	Hydraulic system failures.	265,04	13	DMU50	20,01	13
FM55	Gearbox failures.	264,09	14	DMU58	18,98	14
FM56	Yaw system failures.	260,81	15	DMU60	18,23	15
FM47	Delay in procurement of equipment	235,93	16	DMU53	15,49	16
FM53	Drive train failures.	233,84	17	DMU54	14,46	17
FM60	Control system failures.	215,92	18	DMU55	12,43	18
FM2	Insufficient wind power (Powerless wind)	206,35	19	DMU56	11,3	19
FM54	Generator failures.	191,74	20	DMU24	10,81	20
FM41	Rollever of carrier vehicle	190,73	21	DMU51	3,63	21
FM43	Driver borne problems	190,48	22	DMU62	3,33	22
FM6	Civil unrest and war	187,97	23	DMU01	2,71	23
FM61	Hub failures.	184,24	24	DMU18	1,32	24
FM38	Fall of material during lifting	177,2	25	DMU29	1,31	25
FM12	Credit risk	176,69	26	DMU35	1,12	26
FM52	Mechanical Brake failures.	165,4	27	DMU32	0,73	27
FM8	Suboptimal sitting of wind turbine into the wind farm	163,72	28	DMU33	0,73	27
FM20	Health problems	159,31	29	DMU45	0,67	29
FM34	Dangerous situation	153,65	30	DMU04	0,63	30
FM44	Operator borne problems	152,78	31	DMU25	0,62	31
FM21	Inefficiently working	144,38	32	DMU46	0,62	31
FM42	Rollever of shipment	141,25	33	DMU03	0,61	33
FM39	Moving materials crash	127,97	34	DMU06	0,59	34
FM32	Healthproblems	127,57	35	DMU23	0,57	35
FM50	Structurefailures.	122,68	36	DMU47	0,55	36
FM24	Injury of 3rd person	119,93	37	DMU48	0,54	37
FM33	Waste time	119,41	38	DMU08	0,51	38
FM7	Disagreableturbineselection	118,86	39	DMU05	0,5	39
FM25	Devastate	115,49	40	DMU16	0,5	39

Table 34: Cont.

FMs	Cause of failure	RPN	RANK	DMUs	EFFI-CIENCY	RANK
FM17	Wrongcapacitycalculation	114,14	41	DMU30	0,5	39
FM51	Rotor bladesfailures	109,47	42	DMU36	0,49	42
FM5	Terorism	109,44	43	DMU34	0,47	43
FM3	Birddeaths	103,43	44	DMU09	0,45	44
FM9	Difficulties of emergencyevacuation.	100,35	45	DMU22	0,45	44
FM48	Fire	99,31	46	DMU38	0,45	44
FM26	Broken of equipment	91,918	47	DMU41	0,45	44
FM40	Manuel handling	86,84	48	DMU42	0,44	48
FM37	ElectricalShock	85,7	49	DMU43	0,44	48
FM35	Fall fromhigh	83,618	50	DMU37	0,43	50
FM27	Waste time	79,548	51	DMU40	0,43	50
FM18	Wrongturbinedesign	79,314	52	DMU44	0,43	50
FM49	ElectricShock	76,234	53	DMU17	0,41	53
FM30	Healthproblems	75,808	54	DMU39	0,41	53
FM1	Transportation problem	75,135	55	DMU10	0,39	55
FM62	Safetybladenumbers.	69,266	56	DMU15	0,38	56
FM19	Wrongtechnologyselection	68,49	57	DMU12	0,37	57
FM31	Healthproblems	51,536	58	DMU07	0,34	58
FM36	Difficulties of emergencyevacuation	48,244	59	DMU02	0,33	59
FM4	Diminishing of cultivatableareas	28,8	60	DMU11	0,32	60
FM29	Environmentalpollution	10,918	61	DMU13	0,32	60
FM28	Environmentalpollution	6,437	62	DMU19	0,31	62

By comparing order of the FMs in ranking of original FMEA and SFMEA we realized that instead of starting to take correction actions for FM11 (Foreign Exchange Risk) as the highest risky FM in original FMEA order it is better that we try to fix FM57 (sensor failure), FM26 (Broken Equipment), FM31 (Harming of 3rd parties) and FM 20 (Working a non-ergonomic conditions).

Regarding the required time and cost for corrective actions of FM11 (36.000€ and 365 days) with RPN value of 358.36. It is possible that, by less cost (1.600€ +

100€ + 9.600€= 11.300€) and somehow same time (1 day + 1 day + 1 day + 365 days= 368 days) for corrective actions on FM57, FM26, FM31 and FM20 respectively, we deal with more RPN number (332.48 + 91.918 + 51.536 + 159.312= 635.246).

In the original FMEA the foreign exchange risk is the highest risk but as it known's that for the foreign exchange risk is not possible to intervene in exchange rate so we discussed the other failures which's actionability is possible. In this case fixing sensor failure, broken equipment, harming of 3rd parties and working non ergonomic conditions is seen the corrective actions. These failures' RPN number is more than foreign exchange risk and the cost of these failures' summation is less than the foreign exchange risk. When the solution methods discussed it is clear that reducing the RPN of fixing sensor failure, broken equipment, harming of 3rd parties and working non ergonomic failures are possible with On-the-job training, using the PPE with warning signs and safety controls, periodic maintenance and following up with on-the-job trainings to be given to the employees and the risk assessment analysis which is determined by the OHS specialist.

Chapter 5

CONCLUSION

5.1 Conclusion for Dual Efficiency and Productivity analysis of RE Alternatives of OECD Countries

This study examines the dual efficiency of RE alternatives considering energy dimension, economic dimension, environmental dimension, and social dimension in selected OECD countries for 2012, 2014, and 2016. The study does not only provide analysis on individual RE alternative over time, it provides comparison with other alternatives for more informed decision-making. The analysis has two folds. First which is the most efficient and productive RE alternative in the selected OECD countries? Secondly, which RE alternative is best for a particular county? To analyze efficiency, VRS DEA model was utilized as well as MPI for productivity analysis. First, the result presented for efficiency shows that all RE alternatives were improving in efficiency across the evaluated period. However, bioenergy appears to be the most efficient due to its maximum average efficiency score. Renewable hydro and WE shows significant potential as well. Countries performance in the RE alternatives is non-monolithic. Countries performed differently with regards to the RE alternatives. Therefore, the countries should enhance performance in the RE alternative where they perform better. For example, Bioenergy appears to be the most efficient and productive. However, Italy does better in Renewable hydro compared to bioenergy. Similarly, Turkey does well in Renewable hydro compared to solar and WE. Furthermore, prudent economic policies towards RE and strategic investment are required to improve efficiency. Factors such as installed capacity are covered under the input (Investment capital). Weather conditions are exogenous factors that are beyond the control of the energy systems and should be considered by individual countries. Therefore, weather conditions and resource availability are factors those countries should carefully analyze when deciding on the RE alternative to pursuing in order to achieve RE efficiency.

The present study makes several contributions to the RE efficiency literature. First, it outlines the efficiency dimension of RE systems, and consider indicators that adequately represents the dimension in defining efficiency and productivity of RE. A composite and comprehensive indicator was also introducing to adequately account for the complexity posed by the environmental dimension of RE system. Second, the DEA analysis enhances our understanding of the relative efficiency of RE alternatives, leading to the conclusion that RE efficiency is not monolithic across countries. For instance, Turkey is efficient in renewable-hydro energy, and is inefficient in solar energy, bioenergy and WE. Therefore, Turkey should enhance other RE alternatives if they are to operate a mix RE system. Chile is efficient in bioenergy and inefficient in solar energy, WE, geothermal energy. UK and Sweden had significant improvement in bioenergy and WE in 2016 compared to other periods.

Several noteworthy contributions for policy makers are also provided. First, information context for policy makers aiming to improve efficiency across all RE dimensions. Second, policy makers should understand that RE efficiency tend to be individualistic according to the countries resources potential and not a generic performance. Exogenous factors should also be considered. Lastly, findings of this study provide incentive for policy makers to pursue further development of their efficient RE technologies following the significant growth in efficiency across all RE alternatives.

This study also has a couple of limitations. First, the number of sample countries is not large enough to generalize the findings; however, statistical measures were employed to limit any effects on the results despite it satisfying DEA efficiency evaluation criteria. Data availability was a major constraint in the analysis. Perhaps when countries are fully committed to transition into complete RE systems, efforts towards data availability will improve. Second, the study did not consider economic dimension as an output due to data restriction. Share of RE contribution to economic measures such as GDP could be considered. Future studies should aim to include similar output. In addition, future studies may also consider weight restricted DEA model and stochastic DEA model. However, concrete and evidence-based weight selection should be made before allocating weights to the selected variables. Promethean method or AHP are interesting multi-criteria decision techniques to rank and allocate weights to the decision variables.

5.2 Conclusion for an Extension of SFMEA for WT

WT use renewable and environment friendly resource, the wind, to produce electricity. Therefore, the failure modes of wind farm are a contentious issue. This study presents the most critical failure modes of state-of-the-art offshore wind turbine systems.

This study utilized an Extension of SFMEA for WT. As a direction for further studies, this approach can be applied for other RE resources.

FMEA has been used an effective technique to help assessors to prioritize, identify and prevent potential FMs in the wind turbine industry. The original FMEA has been criticized due to some reasons such as vagueness and uncertainty and inefficiency related to the correction actions and system improvement procedure are initiated. Many approaches mentioned in chapter 2 have been presented to deal with these shortages of original FMEA.

This thesis presented a smart approach to combine the FMEA risk evaluation corrective actions time and cost consumption and DEA models to determine the new order for FMs at which the mentioned gaps of the conventional FMEA is covered. The results have presented the modified approach has some advantages over the original FMEA and can also provide much more information in order to make better discussion to decrease the risk level and subsequently improve the safety performance of the system. Furthermore, the proposed model could guarantee the highest risky FM remains subjective. Then suggested SFMEA approach enables to provide a priority for correction action FMs whose has the high RPN and acceptable time and cost consumption.

In addition, future studies may also consider DEA with fuzzy model instead of Crisp modeling.

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APPENDICES

Appendix 1: FMEA Table of the Experts

NAME AND SURNAME		WEIGHT OF EXPERTS	
AGE		FARM MANAGER	0,470
PERSONAL EXPERIENCE		PROJECT MANAGER	0,301
JOB TENURE		ENGINEER	0,124
PROFESSION		ENGINEER 2	0,058
EDUCATION LEVEL		TECHNICAL PERSON	0,046

WEIGHT OF RPN, 1/RPN AND RANK VALUE

Sub system	Failure modes	Cause of failure	Effects	WEIGHT OF Occurrence (O)	WEIGHT OF Severity (S)	WEIGHT OF Detection (D)	WEIGHT OF RPN (= OxSxD)	RPN	1/RPN	RANK	Detection method	Solution recommended to reduce the RPN	Approximative cost of the solution	Approximate time needed to apply the solution
FEASIBILITY STUDY	Choosing an inappropriate wind farm area	Transportation problem	Waste time and energy	5,981	6,707	1,775	75,135	75,135	0,013309376	55	Access route assessment during feasibilty study.	Early detection to choose the right routes and, if necessary, shortcut road construction.	According to the calculation that 1 ton asphalt is approximately 350 TL. For 30 km length and 2 m wide road with 15 cm thickness around 9.000 m3 asphalt is required. If 1 ton of asphalt covers an area of 26m2, 2,307.69 tons of asphalt is required for 30,000*2 = 60,000m2. Approximately cost 808,000 TL / **81,000€**	60 days
		Insufficient wind power (Powerless wind)	Capacity and Profit	5,433	7,432	5,529	206,354	206,354	0,004846041	19	Wind measurement should be made at the right height in accordance with international standards.	To make wind measurements during the feasibility study and to start the project if the measurement results are sufficient. 1 year measurements are necessary..	Wind measurement is required for 1 year with the installation of a wind measurement pole. The cost of the pole is 120.000 TL, if we consider 40% of the cost of the installation, the cost of construction and a staff for its follow-up; 120.000*140/100+5000*12 (Salary) = approximately 230.000 TL / **22.000 €**	365 days
		Bird deaths	Environment	5,043	9,358	2,26	103,426	103,426	0,009668749	44	Monitoring/research of birds and bats during R&D, construction process and facility operation. To be in transparent communication with the local people.	Making changes in the layout or applying restrictions with early detection.	Penalties for bird deaths can range from €50,000 to €500,000 depending on the country. If we consider the cost of the survey and monitoring process as the annual salary of a person who will analyze the process; 12 * 5000 TL = 60.000 TL. / **6,000€**	365 days
		Diminishing of cultivatable areas	Environment	2,311	7,548	2,337	28,8	28,8	0,034722222	60	Obtaining opinions from the ministry of agriculture and forestry and local people.	Resettlement plan according to good relations with farmers, transparent communication and feasibility studies.	It may vary by country and region, but there is no extra cost. Permits and other researches approximate cost is **5000€**	365 days
		Terorism	Profit and cost	3,375	8,912	3,691	109,436	109,436	0,009137761	43	Consultation with local authorities.	Ensuring security with soldiers, police and guards.	It may vary by country and region, but there is no extra cost. Permits and other researches approximate cost is **5000€**	365 days
		Civil unrest and war	Cost	3,702	7,167	5,682	187,972	187,972	0,005319941	23	Consultation with local authorities and local people.	To ensure good relations with the local people, transparent communication and transparent monitoring of the activities.	It may vary by country and region, but there is no extra cost. Permits and other researches approximate cost is **5000€**	365 days
	Choosing an inappropriate wind turbine	Disagreable turbine selection	Capacity and Profit	3,022	8,918	4,183	118,858	118,858	0,008413401	39	Selection of turbines with the appropriate technical specifications with the site evaluation report and technical analysis of the wind regime.	Making the selection of a turbine by calculating the capacity factors according to the wind characteristics of the field, by consulting the experts on the site evaluation report and the selection of turbines with suitable characteristics.	Calculation of capacity factors (according to the calculation that it is measured with 4 anemometers, if we consider that an engineer analyzes the measurements on 2 different wind masts; 120.000*140/100*(2 pcs)+850*4(4 pcs anemometers) +5000*12(annual) for pole installation salary)= 400.000tl / **40.000€**	365 days
	Wind turbine sitting mistake	Suboptimal sitting of wind turbine into the wind farm	Capacity and Profit	5,772	9,492	2,873	163,718	163,718	0,006108064	28	CFD wind modeling and production simulation software are used for proper turbine placement (Micrositting).	Determination of micrositing-layout plan.	The cost of implementing the micrositing layout plan is approximately 200,000 TL / **20.000€**	365 days
		Difficulties of emergency evacuation.	Health	2,853	9,226	3,165	100,354	100,354	0,009964725	45	Establishing an emergency and evacuation plan.	Establishing an emergency and evacuation plan and identifying possible problems with drills. Training of employees	On-the-job trainings to be given to the employees and the risk assessment map to be determined by the OHS expert, and exercises are carried out at certain intervals. Reporting nonconformities as a result of observations and taking corrective and preventive actions. (1 ISG specialist can do it with a salary of approximately 8000 TL.) / **9600€ (annual)**	365 days

Appendix 1: Cont.

NAME AND SURNAME	
AGE	
PERSONAL EXPERIENCE	
JOB TENURE	
PROFESSION	
EDUCATION LEVEL	

WEIGHT OF EXPERTS	
FARM MANAGER	0,470
PROJECT MANAGER	0,301
ENGINEER	0,124
ENGINEER 2	0,058
TECHNICAL PERSON	0,046

WEIGHT OF RPN, 1/RPN AND RANK VALUE

Sub system	Failure modes	Cause of failure	Effects	WEIGHT OF Occurrence (O)	WEIGHT OF Severity (S)	WEIGHT OF Detection (D)	WEIGHT OF RPN (= OxSxD)	RPN	1/RPN	RANK	Detection method	Solution recommended to reduce the RPN	Approximative cost of the solution	Approximate time needed to apply the solution
FEASIBILITY STUDY	Unexpected investment cost	Calculating mistake of investment costs	Cost	4,559	9,446	5,318	271,54	271,54	0,003682699	12	Receiving a price quote on CAPEX/OPEX during the feasibility study. Working with an experienced and experienced team plays an important role.	All cost items to be taken into account during the feasibility study should be calculated in detail with the team to be composed of experts in the field.	Monte Carlo Simulation Planning and project management costs are approximately 30.000€	365 days
		Foreign exchange risk	Cost	6,579	9,84	6,673	358,362	358,362	0,002790474	1	Economic and political risk assessments	Minimizing the losses that will arise from the exchange rate difference by taxiing the receivables in foreign currency when the exchange rate is high and making the payments in foreign currency when the exchange rate decreases.	Finance Specialist and his team. Approximate cost is 360.000 TL per year / 36.000€	365 days
		Credit risk	Cost	3,323	8,934	5,769	176,692	176,692	0,005659566	26	Economic and political risk assessments	Examining loan and interest rates, Getting a loan in TL, Providing the necessary conditions for receiving appropriate incentives, Borrowing prevention.	Finance Specialist and his team. Approximate cost is 360.000 TL per year / 36.000€	365 days
		Inflation risk	Cost	8,536	7,517	5,921	355,676	355,676	0,002811548	2	Economic and political risk assessments	Estimated of inflation rate	Finance Specialist and his team. Approximate cost is 360.000 TL per year / 36.000€	365 days
		Electricity price risk	Cost	8,103	8,108	5,236	320,6	320,6	0,003119152	8	EPDK determines.	The increase in the electricity fee is an advantageous situation for the WPP investor.	There is not any cost. 0€	365 days
		Expensive spare parts	Cost	8,314	8,816	4,571	349,672	349,672	0,002859823	3	Researching of price.	Researching of price, Prefer local productions, To determine safety stock for parts that are used continuously.	Since domestic productions are in TL and there will be no transportation and customs costs, they will be discounted at the rate of 20% per piece. If we consider that the annual maintenance cost is 300.000 € than benefit of us will be 60.000€ ; 60.000€	365 days
		Change of law and regulations.	Management	6,539	7,85	5,617	299,518	299,518	0,003338698	9	Following of the laws and regulations regularly.	By following the changes in the laws and laws related to the activity; To implement the actions to be taken during the activity or the revisions to be made within the legal time limit.	It may vary by country and region, but there is no extra cost. Permits and other researches approximate cost is 5000€	365 days
Technological	Technical and Engineering design mistakes	Wrong capacity calculation	Capacity and co	4,296	8,61	3,075	114,14	114,14	0,00876117	41	Calculation of capacity.	Capacity calculation should be done during the feasibility study with the team that will be composed of experts in the field.	Calculation of capacity factors (according to the calculation that it is measured with 4 anemometers, if we consider that an engineer analyzes the measurements on 2 different wind masts; 120.000*140/100*(2 pcs)+850*4(4 pcs anemometers) +5000*12(annual) for pole installation salary)= 400.000tl / 40.000€	365 days
		Wrong turbine design	Capacity and co	2,913	7,754	3,359	79,314	79,314	0,012608115	52	Feasibility studies	Making the capacity planning of the facility to be established within the scope of feasibility studies and choosing the optimum turbine that will meet the need for the facility. Making the most appropriate placement so that we can achieve maximum efficiency.	Turbine design belongs to the supplier company. At this point, only the cost of providing the most appropriate placement in order to achieve maximum efficiency. The cost of implementing the micrositing layout plan is approximately 200,000 TL / 20.000€	90 days

Appendix 1: Cont.

ME AND SURNAME						WEIGHT OF EXPERTS		WEIGHT OF RPN, 1/RPN AND RANK VALUE						
E						FARM MANAGER	0,470							
RSONAL EXPERIENCE						PROJECT MANAGER	0,301							
B TENURE						ENGINEER	0,124							
OFESSION						ENGINEER 2	0,058							
UCATION LEVEL						TECHNICAL PERSON	0,046							
Sub system	**Failure modes**	**Cause of failure**	**Effects**	**WEIGHT OF Occurrence (O)**	**WEIGHT OF Severity (S)**	**WEIGHT OF Detection (D)**	**WEIGHT OF RPN (= OxSxD)**	**RPN**	**1/RPN**	**RANK**	**Detection method**	**Solution recommended to reduce the RPN**	**Approximative cost of the solution**	**Approximate time needed to apply the solution**
Technological	Advancement of alternative technologies may render other energy sources more feasible	Wrong technology selection	Capacity and co	2,625	8,072	3,355	68,49	68,49	0,014600672	57	Selection of the most suitable energy source for the region and the size of the facility during the feasibility study.	Making observations and analyzes before starting the project, Exchange of information from local people, Exchange of information with local authorities.	Project's analysis cost 45.000€	365 days
Ergonomics	Working non ergonomic conditions	Health problems	Health	5,266	9,11	3,239	159,312	159,312	0,006276991	29	Ergonomics studies that can be applied to increase productivity	Evaluating suggestions and requests regarding the work that can be applied according to the nature of the work to be done in terms of ergonomics. Evaluation if there is a situation to be developed within the scope of productivity increase and improvement projects. Organizing activities in 5S/Kaizen and lean philosophy.	Risks that may occur in terms of health can be followed up with on-the-job trainings to be given to the employees and the risk assessment analysis to be determined by the OHS specialist. In addition, it is very valuable for the business manager to support productivity and innovation projects for efficiency. It is equal to the annual cost of the ISG specialist. 9600€ (annual).	365 days
	Working in confined spaces	Inefficiently working	Health and cost	7,43	6,867	2,768	144,376	144,376	0,006926359	32	Ergonomics studies that can be applied to increase productivity	Evaluating suggestions and requests regarding the work that can be applied according to the nature of the work to be done in terms of ergonomics. Evaluation if there is a situation to be developed within the scope of productivity increase and improvement projects. Organizing activities in 5S/Kaizen and lean philosophy.	Risks that may occur in terms of health can be followed up with on-the-job trainings to be given to the employees and the risk assessment analysis to be determined by the OHS specialist. In addition, it is very valuable for the business manager to support productivity and innovation projects for efficiency. It is equal to the annual cost of the ISG specialist. 9600€ (annual)	365 days
Environmental	Fire risk	Electrical failures.	Cost	7,42	9,428	5,073	344,656	344,656	0,002901444	5	Technical control	It needs to be detected without downtime with planned maintenance and controls.	Annual periodic operating and maintenance cost is approximately 8.000€	365 days
		Strike of lightning	Cost	6,676	8,188	3,833	344,656	344,656	0,002901444	5	Lightning detection systems, Lightning Rod	It is a big problem in the industry as insurance companies do not cover lightning strikes and turbine suppliers do not take enough responsibility. Contractual agreements must be made. Lightning detection systems, alarms, lightning rods, copper leads and strips should be used.	Lightning rod cost is approximately annual 7000€	365 days
	Icing risk	Injury of 3rd person	Health	2,547	7,594	3,927	119,926	119,926	0,008338475	37	Icing causes energy production to decrease or to stop completely, turbines to get mechanically tired faster and throwing ice poses a danger to surrounding structures and living things.	Sufficient distance from residential areas, warning signs, restriction. Investing in anti-icing Establishment of ice detection system.	The ice detection system measures the amount of ice buildup on the rotor blades and ensures reliable operation for the wind turbine generator. If 1 sensor is thought to be 50€; Approximate cost seasonal 200€	120 days
	Natural disaster	Devastate	Cost	2,501	9,428	4,445	115,486	115,486	0,008659058	40	During the project phase, opinions should be obtained from local people and disaster directorates.	Opinions should be sought from disaster directorates. Transparent communication with local people is important. Buildings should be constructed in accordance with the permits and zoning plans received at the project stage.	Cost of project engineering and legal permits 5000€	365 days

Appendix 1: Cont.

NAME AND SURNAME	
AGE	
PERSONAL EXPERIENCE	
JOB TENURE	
PROFESSION	
EDUCATION LEVEL	

WEIGHT OF EXPERTS	
FARM MANAGER	0,470
PROJECT MANAGER	0,301
ENGINEER	0,124
ENGINEER 2	0,058
TECHNICAL PERSON	0,046

WEIGHT OF RPN, 1/RPN AND RANK VALUE

Sub system	Failure modes	Cause of failure	Effects	WEIGHT OF Occurrence (O)	WEIGHT OF Severity (S)	WEIGHT OF Detection (D)	WEIGHT OF RPN (=OxSxD)	RPN	1/RPN	RANK	Detection method	Solution recommended to reduce the RPN	Approximative cost of the solution	Approximate time needed to apply the solution
Environmental	Freezing of equipments's fuels	Broken of equipment	Cost	2,389	6,48	5,083	91,918	91,918	0,010879262	47	It may vary depending on weather conditions. The equipment supervisor should definitely check it.	Necessary training should be given to equipment supervisors and periodic controls should be provided by the equipment supervisor. Use of antifreeze.	Since support will be received from the existing employees for the controls, there is no cost, but if it is considered as 1 € per liter for the antifreeze agent, the approximate cost for the consumption of 1000 liters per year. 100€	1 day
		Waste time	Cost	2,375	6,238	4,775	79,548	79,548	0,012571026	51	It may vary depending on weather conditions. The equipment supervisor should definitely check it.	Necessary training should be given to equipment supervisors and periodic controls should be provided by the equipment supervisor.	Since support will be received from the existing employees for the controls, there is no cost, but if it is considered as 1 € per liter for the antifreeze agent, the approximate cost for the consumption of 1000 liters per year. 100€	1 day
	Gas emission	Environmental pollution	Environment	0,999	4,087	1,469	6,437	6,437	0,155351872	62	Thanks to periodic controls, it can be detected by gas leakage measurement method.	Necessary training should be given to field supervisors and periodic controls should be provided in areas that may cause gas leakage. Gas sensor installation at critical points.	There is no cost as support will be received from existing employees for the controls. But for gas meter and sensor cost per year 1000€	1 day
	Geothermal waste risk	Environmental pollution	Environment	0,999	6,292	1,77	10,918	10,918	0,091591867	61	Obtaining the permits of an activity in accordance with the procedure by the Ministry of Environment during the feasibility phase of the project.	It is known by the literature studies and relevant authorities that there is no risk.	It may vary by country and region, but there is no extra cost. Permits and other researches approximate cost is 5000€	365 days
	Noise	Health problems	Environment	3,695	7,938	2,121	75,808	75,808	0,01319122	54	Decibel measurements with dosimeters	Mechanical and aerodynamic noises occur. With planned maintenance for mechanical noise, malfunctions that may cause noise in the mechanical parts can be prevented.	The approximate cost of periodic maintenance and turbine equipment replacement in new technology 10.000€	365 days
	Harming of 3rd parties	Health problems	Health	1,957	8,9	2,905	51,536	51,536	0,019403912	58	Use of PPE with warning signs and safety controls	On-the-job training should be provided. Personal protection and equipment should be used. Field inspections by the OHS expert should be increased.	On-the-job training, The use of PPE with warning signs and safety controls is approx 1000€	1 day
	Work accidents because of weather conditions	Health problems	Cost	3,079	9,944	4,938	127,574	127,574	0,007838588	35	In maintenance activities that continue throughout the year, extremely hot and cold weather conditions can lead to occupational accidents, especially during working at height.	Limitation of operating conditions (high wind speed definition, etc.)	On-the-job training, The use of PPE with warning signs and safety controls is approx 3000€	365 days
		Waste time	Cost	3,071	8,983	4,826	119,408	119,408	0,008374648	38	In maintenance activities that continue throughout the year, extremely hot and cold weather conditions can lead to occupational accidents, especially during working at height.	Limitation of operating conditions (high wind speed definition, etc.)	On-the-job training, The use of PPE with warning signs and safety controls is approx 3000€	365 days
	Emergency evacuation fo	Dangerous situation	Health	2,885	9,944	5,944	153,648	153,648	0,006508383	30	Establishing an emergency and evacuation plan.	Establishing an emergency and evacuation plan and identifying possible problems with drills. Providing training to employees	On-the-job trainings to be given to the employees and the risk assessment map to be determined by the OHS expert, exercises are carried out at certain periods; Reporting nonconformities as a result of observations and taking corrective and preventive actions. (1 ISG specialist can do it with a salary of about 8000 TL.) / 9600€ (annual)	365 days

Appendix 1: Cont.

NAME AND SURNAME	
AGE	
PERSONAL EXPERIENCE	
JOB TENURE	
PROFESSION	
EDUCATION LEVEL	

WEIGHT OF EXPERTS	
FARM MANAGER	0,470
PROJECT MANAGER	0,301
ENGINEER	0,124
ENGINEER 2	0,058
TECHNICAL PERSON	0,046

WEIGHT OF RPN, 1/RPN AND RANK VALUE

Sub system	Failure modes	Cause of failure	Effects	WEIGHT OF Occurrence (O)	WEIGHT OF Severity (S)	WEIGHT OF Detection (D)	WEIGHT OF RPN (= OxSxD)	RPN	1/RPN	RANK	Detection method	Solution recommended to reduce the RPN	Approximative cost of the solution	Approximate time needed to apply the solution
Technical	Accident	Fall from high	Health	1,965	9,342	4,436	83,618	83,618	0,011959148	50	On-the-job trainings and inspections of OHS experts should prevent problems in practice.	On-the-job training should be provided. Personal protection and equipment should be used. Field inspections by the OHS expert should be increased.	Preventing accidents with the use of personal protective equipment and on-the-job training. 3000€	365 days
		Difficulties of emergency evacuation	Health	2,111	9,25	2,18	48,244	48,244	0,020727966	59	Establishing an emergency and evacuation plan.	Establishing an emergency and evacuation plan and identifying possible problems with drills. Providing training to employees	On-the-job trainings to be given to the employees and the risk assessment map to be determined by the OHS expert, exercises are carried out at certain periods; Reporting nonconformities as a result of observations and taking corrective and preventive actions. (1 ISG specialist can do it with a salary of about 8000 TL.) / 9600€ (annual)	365 days
		Electrical Shock	Health	2,676	9,886	3,639	85,7	85,7	0,011668611	49	Technician control	It can be detected in periodic maintenance.	Electrical system failure 8.000€	3 days
		Fall of material during lifting	Health	5,526	8,648	3,985	177,202	177,202	0,005643277	25	Creating an transportaion instructions.	On-the-job trainings to be given to the employees. The risks that may occur during the transportation of the material are analyzed and appropriate transportation instructions are created.	On-the-job trainings and a risk assessment map are created by the OHS expert. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the ISG specialist. 9600€ (annual)	365 days
		Moving materials crash	Cost	2,972	8,329	5,192	127,968	127,968	0,007814454	34	Creating an transportaion instructions.	On-the-job trainings to be given to the employees. The risks that may occur during the transportation of the material are analyzed and appropriate transportation instructions are created.	On-the-job trainings and a risk assessment map are created by the OHS expert. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the ISG specialist. 9600€ (annual)	365 days
		Manuel handling	Health	2,419	6,133	6,414	86,84	86,84	0,011515431	48	Creating an transportaion instructions.	On-the-job trainings to be given to the employees. The risks that may occur during the transportation of the material are analyzed and appropriate transportation instructions are created.	On-the-job trainings and a risk assessment map are created by the OHS expert. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the ISG specialist. 9600€ (annual)	365 days
		Rollever of carrier vehicle	Cost	3,961	8,009	6,058	190,732	190,732	0,005242959	21	Creating an transportaion instructions.	On-the-job trainings to be given to the employees. The risks that may occur during the transportation of the material are analyzed and appropriate transportation instructions are created.	On-the-job trainings and a risk assessment map are created by the OHS expert. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the ISG specialist. 9600€ (annual)	365 days
		Rollever of shipment	Cost	3,016	8,055	6,058	141,248	141,248	0,007079746	33	Creating an Load carring instructions.	On-the-job trainings to be given to the employees. The risks that may occur during the load carring of the material are analyzed and appropriate load carring instructions are created.	On-the-job trainings and a risk assessment map are created by the OHS expert. It is fixed during transportation by being tied with ropes appropriately. Its approximate cost is as much as the annual cost of the ISG specialist. 9600€ (annual)	365 days
		Driver borne problems	Health	4,1	7,453	6,155	190,48	190,48	0,005249895	22	Rules to be followed while driving	By doing on-the-job trainings and risk analysis that may occur; The rules to be followed while driving are determined.	On-the-job trainings and a risk assessment map are created by the OHS expert. Its approximate cost is as much as the annual cost of the ISG specialist. 9600€ (annual)	365 days
		Operator borne problems	Health	3,44	8,055	5,659	152,778	152,778	0,006545445	31	On-the-job training of the operator and instructions that the operator must follow	On-the-job training and analysis of the risks that may occur are made. The rules that the operator must comply with are determined during the work.	On-the-job trainings and a risk assessment map are created by the OHS expert. Its approximate cost is as much as the annual cost of the ISG specialist. 9600€ (annual)	365 days

Appendix 1: Cont.

ME AND SURNAME		
E		
SONAL EXPERIENCE		
TENURE		
FESSION		
CATION LEVEL		

WEIGHT OF EXPERTS	
FARM MANAGER	0,470
PROJECT MANAGER	0,301
ENGINEER	0,124
ENGINEER 2	0,058
TECHNICAL PERSON	0,046

WEIGHT OF RPN, 1/RPN AND RANK VALUE

Sub system	Failure modes	Cause of failure	Effects	WEIGHT OF Occurrence (O)	WEIGHT OF Severity (S)	WEIGHT OF Detection (D)	WEIGHT OF RPN (= OxSxD)	RPN	1/RPN	RANK	Detection method	Solution recommended to reduce the RPN	Approximative cost of the solution	Approximate time needed to apply the solution
Technical	Repair/Maintenance	Unexpected maintenance	Cost and waste	4,144	8,643	8,003	294,968	294,968	0,003390198	10	Periodic controls and maintenance.	It is detected in periodic controls and maintenance.	Periodic operation and maintenance cost. 5.000€	365 days
		Unexpected extension of periodic maintance periods	Cost and waste	5,951	7,995	6,383	347,203	347,203	0,002880159	4	Planned maintenance	Minimizing the time with planned maintenance and spare parts supply. Maintaining critical safety stock of necessary parts for recurring failures.	Periodic maintenance cost 4.000€	365 days
		Delay in procurement of equipment	Cost and waste	4,999	8,211	5,615	235,933	235,933	0,004238491	16	Planned maintenance	Minimizing the time with planned maintenance and spare parts supply.	Periodic operation and maintenance cost 5.000€	365 days
		Fire	Cost	2,134	8,534	4,675	99,31	99,31	0,010069479	46	Technician control	It will be detected without downtime with planned maintenance and controls.	Annual periodic operating and maintenance cost is approximately 8.000€	365 days
		Electric Shock	Cost	2,514	9,041	4,048	76,234	76,234	0,013117507	53	Technician control	It can be detected in periodic maintenance.	Electrical system failure 8.000€	3 days
	Component failure	Structure failures.	Cost	4,904	8,806	3,282	122,68	122,68	0,008151288	36	Planned maintenance	It can be detected in periodic maintenance.	Structure failures's cost 3.800€	7 days
		Rotor blades failures	Cost	2,666	8,168	4,954	109,468	109,468	0,00913509	42	Planned maintenance	It can be detected in periodic maintenance.	Rotor Blade's Cost 6.000€	30 days
		Mechanical Brake failures.	Cost	2,48	9,84	6,856	165,402	165,402	0,006045876	27	Planned maintenance	It can be detected in periodic maintenance.	Mechanical brake failure's cost 60€	7 days
		Drive train failures.	Cost	4,458	9,794	5,617	233,844	233,844	0,004276355	17	Planned maintenance	It can be detected in periodic maintenance.	Drive train failure's cost 3.000€	8 days
		Generator failures.	Cost	3,602	9,5	5,753	191,74	191,74	0,005215396	20	Planned maintenance	It can be detected in periodic maintenance.	Generatör failure's cost 8.760€	9 days
		Gearbox failures.	Cost	4,766	9,84	5,741	264,088	264,088	0,003786617	14	Planned maintenance	It can be detected in periodic maintenance.	Gear Box failure's cost 3.000€	10 days
		Yaw system failures.	Cost	5,035	8,888	6,041	260,812	260,812	0,003834179	15	Planned maintenance	It can be detected in periodic maintenance.	Yaw system failure's cost 1.500€	11 days
		Sensor failures.	Cost	6,811	7,77	6,293	332,48	332,48	0,0030077	7	Planned maintenance	It can be detected in periodic maintenance.	Sensör failure's cost 1.600€	1 day
		Hydraulic system failures.	Cost	5,104	9,69	5,667	265,044	265,044	0,003772958	13	Planned maintenance	It can be detected in periodic maintenance.	Hydraulic system's failure cost 480€	7 days
		Electrical system failures.	Cost	4,77	9,794	6,365	293,4	293,4	0,003408316	11	Planned maintenance	It can be detected in periodic maintenance.	Electrical system's failure cost 1.600€	3 days
		Control system failures.	Cost	4,058	9,678	5,817	215,924	215,924	0,004631259	18	Planned maintenance	It can be detected in periodic maintenance.	Control system's failure cost 3.000€	7 days
		Hub failures.	Cost	3,016	9,84	6,365	184,244	184,244	0,005427585	24	Planned maintenance	It can be detected in periodic maintenance.	Hub's failure cost 2.560€	7 days
		Safety blade numbers.	Cost	2,311	7,006	4,259	69,266	69,266	0,014437098	56	Planned maintenance	It can be detected in periodic maintenance.	Safe Blade's cost 6.000€	30 days

Appendix 2: Experts Weighting

A MATRIX

PAIR-WISE COMPARISION	FARM MANAGE R	PROJECT MANAGER	ENGI NEER	ENGIN EER 2	TECHNICAL PERSON
FARM MANAGER	1,000	3,000	5,000	7,000	6,000
PROJECT MANAGER	0,333	1,000	4,000	7,000	7,000
ENGINEER	0,200	0,250	1,000	4,000	3,000
ENGINEER 2	0,143	0,143	0,250	1,000	2,000
TECHNICAL PERSON	0,167	0,143	0,333	0,500	1,000
TOTAL	1,843	4,536	10,58 3	19,500	19,000

N_A MATRIX

PAIR-WISE COMPARISION	FARM MANAGE R	PROJECT MANAGER	ENGI NEER	ENGIN EER 2	TECHNICAL PERSON	CRITERIA WEIGHT
FARM MANAGER	0,543	0,661	0,472	0,359	0,316	0,470
PROJECT MANAGER	0,181	0,220	0,378	0,359	0,368	0,301
ENGINEER	0,109	0,055	0,094	0,205	0,158	0,124
ENGINEER 2	0,078	0,031	0,024	0,051	0,105	0,058
TECHNICAL PERSON	0,090	0,031	0,031	0,026	0,053	0,046

PAIR-WISE COMPARISION	FARM MANAGE R	PROJECT MANAGER	ENGI NEER	ENGIN EER 2	TECHNICAL PERSON	TOTAL
FARM MANAGER	0,470	0,904	0,621	0,405	0,278	2,678
PROJECT MANAGER	0,157	0,301	0,497	0,405	0,324	1,684
ENGINEER	0,094	0,075	0,124	0,231	0,139	0,664
ENGINEER 2	0,067	0,043	0,031	0,058	0,093	0,292
TECHNICAL PERSON	0,078	0,043	0,041	0,029	0,046	0,238

TOTAL	CRITERIA WEIGHT	T/J	AVERAGE	LAMDA MAX	CONSISTENCY INDEX
2,678	0,470	5,6955	5,3625	5,3625	0,090634301
1,684	0,301	5,5892			
0,664	0,124	5,3448			0,081286368
0,292	0,058	5,0453			< 0,10
0,238	0,046	5,1379			SO THAT IS ACCEPTABLE

Consistency Index (CI):

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

λ_{max}: Principal Eigenvalue

n: dimension of the matrix

Random Consistency Index (RI):

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,525	0,882	1,115	1,252	1,341	1,404	1,452	1,484

Appendix 3: PIM-DEA Software