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A Comparison of Risks Assessment for the Project Phase of Solar Power Plant Installation with FMEA Pareto and AHP Methods

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Abstract
As a result of the rapid depletion of fuels, high costs and environmental concerns which is in today's conditions in energy production by traditional methods cause rapid orientation to renewable energy sources. In this context, the number of alternative researches and studies on the phenomenon of energy, which has become an indicator of the development of countries, has increased steadily. Taking measures by analysing possible failures and risks in the establishment and operation of renewable energy plants is of great importance in terms of cost control, efficiency, sustainability of production and ensuring the safety of life and property. For this reason, in this study, failures and risks occurring in the projecting stage, which is the first and important stage of the installation of solar power plants (SPP), which are among the sustainable and renewable energy sources that have become an important part of our lives are analysed using Failure Mode Effect Analysis (FMEA). In the FMEA analysis, the precautions that can be taken against the mistakes and risks that may be encountered regarding the researched subject were investigated. In addition, the opinions of experts on this subject expressed in the literature and researches were also taken into consideration. Then, with the Pareto analysis and Analytical Hierarchy Process (AHP) method systematic, the order of importance of the risks was determined and the similarities between them were tried to be determined.

1. Introduction

In recent years, the need for electrical energy in developed and developing countries has been increasing in every field. The increase in demand for electrical energy due to the rapid development of industrialization and technology has become more noticeable with the increase in the quality of life in cities. The increase in the need for electrical energy causes a rapid decrease in fossil underground resources that cannot be renewed and consequently to be depleted in the future. For this reason, it is also important to use alternative and renewable energy sources instead of traditional and depletable fossil fuels in the production of sustainable and environmentally friendly electricity [1]. Thanks to renewable energy sources, electricity needs are met and at the same time, nature and living creatures are protected and furthermore, an undeniable assistance is provided to prevent global climate change. Solar energy is one of the renewable energy sources because it is environmentally friendly and has been preferred in recent years due to its ease of use and high potential. The carbon level is increasing due to the use of various technologies. Therefore, solar energy, which does not cause carbon emissions and protects nature, has become an energy type that countries have invested in [2]. In their study, [3], regarding the integration of the system used in concentrated solar power plants to the thermal power

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plant using coal, demonstrated that this hybrid system can be economical. Regarding the preference of solar energy power plants (SPP) that generate electricity using solar energy, the following aspects are the main reasons that should be considered:

- Solar energy is one of the non-depletable sources of energy.
- The usage areas of solar energy are diverse in the fields of electricity generation, heating, cooling, drying, lighting, calculators, clocks and energy supply of traffic sign lamps, producing hot water, distilling water, charging mobile phones batteries, portable power supplies, and cooking etc. [4],
- Since solar energy applications are completely natural, there is no harm to the environment,
- Since it is easy to generate electricity from solar energy, any person can produce his own electricity with solar energy without requiring professionalism,
- The installation of SPP facilities is easy and it is possible to establish these facilities in approximately 1-9 months depending on the plant capacity,
- Maintenance of SPP facilities is easy; in addition, operation and maintenance costs are low,
- Due to the construction with durable materials, photovoltaic solar panels can resist harsh weather conditions [5].

Compliance of the installation site with the power plant project is of great importance in all stages of the plan-project, installation, activation and operation of the power plants that produce electricity from solar energy. Therefore, in the SPP plan-project, installation, activation, operation and maintenance stages of the power plant; Conditions such as the location of the power plant and the topographic conditions of the land, weather conditions, basic engineering, geological and geotechnical features of the installation site, material supply and material properties, technical calculations of the power plant, placement of panels and inverters, annual maintenance and monitoring should be taken into consideration. Sustainability is of great importance in electrical energy generation. Unless sustainability of a non-depletable and endless energy source like the sun is ensured, sustainability will not be achieved in electrical energy generation [6]. For this reason, as in all renewable energy sources, the risks, failures and problems that may be encountered in the production of electricity with solar energy, should be clearly revealed, analyzed and solution suggestions should be determined in order to avoid these risks and failures before they occur. Successful completion of the plan-project phase, which is the first step in the SPP installation, determining the installation area and ensuring its compatibility with the facility, determining the possible risks that may be encountered and taking measures against these risks; has positive effects in terms of the safety, efficiency, life cycle of the planned power plant, keeping the project cost at the level determined and ensuring sustainability in electricity generation. For this reason, in this study, failures and risks that may be encountered in the SPP plan-project phase were investigated by means of failure mode and effects analysis (FMEA), Pareto and analytical hierarchy process (AHP) systematic and the results obtained were compared.

In literature studies, it is seen that many risk analysis studies such as Fault Tree Analysis (FTA), Weighted Sum Method (WSM), Strengths, weaknesses, opportunities and threats analysis (SWOT), AHP, FMEA, Pareto methods for identifying the risks that may occur in projects targeting electrical energy production using renewable energy resources, have been conducted in order to increase efficiency [7]. [8] conducted a risk analysis study using fuzzy FMEA technique in the use of renewable energy resources. In their studies, they calculated the risk priority numbers (RPN) with FMEA techniques by classifying the risks related to solar, wind and geothermal energy in terms of environmental, financial, technological aspects and construction and operation features. In wind power plant (WPP) projects, one of the renewable energy types, [1] examined failures and risks arising in aerial photography and mapping activities. [9] showed in their study that FMEA techniques provide a more realistic risk analysis to revise the maintenance plan of photovoltaic plants and optimize their efficiency. [10] has studied failure probabilities for SPP photovoltaic systems using FMEA method and revealed that the FMEA approach is a protective method in photovoltaic applications. [11] has determined that there will be an increase in the amount of energy produced by using a thermoelectric cooler in the photovoltaic panel. [12] as a result of his research on FMEA analysis of solar modules, proposed the FMEA method in order to increase the efficiency of solar modules. [13] investigated the suitability for solar farms of Ulleung Island in Korea using Geographical Information Systems (GIS), Fuzzy Sets and AHP. [14] evaluated to economic, environmental and social factors in their study using

AHP and Fuzzy-VIKOR methods in some solar projects in Türkiye.

In this study, the possible risks that may arise in the plan-project stages of SPP projects and the measures that can be taken to prevent these possible risks have been investigated. For this, the opinions of the experts in these subjects in the literature and researches were also taken into consideration. In addition, graphical reviews of these investigated risks were made by ranking their importance within the Pareto analysis. In addition, these risks were re-examined with the AHP method and comparisons of the results specific to the methods were performed. Consequently a new contribution was tried to be made to the literature.

2. Material and Method

2.1. Risk Parameters Used in Analysis

In Solar Power Plant (SPP) construction projects; there are stages such as plan-project, installation, commissioning, operation and maintenance of the power plant. In this study, it is aimed to pre-define the negativities that may arise from the risks that may occur while the SPP plan-project and design phase is carried out. In this study, it is aimed to predefine the risks that may occur during the planning phase of SPP projects. For this reason, the opinions of those who have expertise in SPP projects, (such as map / geodesy and photogrammetry / geomatics, geology, construction, geophysics, machinery, industrial engineers) expressed in the literature and researches, are also considered. As a result, it has been observed that possible failures and risks listed below have been encountered.

- Process No: A1- Failures and risks in solar radiation measurement and determination of weather conditions according to the location of the region,
- Process No: A2- Failures and risks arising from the lack of maps of the land to be installed or the lack and inaccuracies in the maps, (topographic, settlement, vegetation, geology, etc.)
- Process No: A3- Failures and risks made in the slope and aspect calculation of the land where the SPP will be built,
- Process No: A4- Failures and risks made in explaining the geological structure of the land where the SPP will be installed,
- Process No: A5- Lack, failures and risks in the geotechnical and static analysis of the land where the SPP will be installed,
- Process No: A6- Failures and risks in the detection and measurement of the existing and potential landslides of the land where the SPP will be installed,
- Process No: A7- Failures and risks made in the drainage system of the land where a SPP will be installed,
- Process No: A8- Failures and risks in cadastral and ownership / expropriation measurements of the land where SPP will be installed,
- Process No: A9- Failures and risks in calculating the distance of the system to be installed to the distribution lines and center,
- Process No: A10- Failures and risks arising from delays in obtaining permits.

2.2. Failure Mode and Effects Analysis (FMEA), Pareto Analysis, Analytic Hierarchy Process (AHP)

Although there is no standard method for the analysis of risks by hand in SPP facility projects, it is of great importance to create sensitive data, to determine standard comparison criteria, to apply risk analysis methods that are accepted in the literature and have also been successful as a result of the application. Many unexpected risk factors can be encountered in the installation of a solar power plant. For this reason, the risk analysis to be applied in these projects is of great importance in terms of completing the SPP installation on time, keeping the project cost at a specified level, working in a healthy environment and ensuring the continuity of production. FMEA is a systematic method used to identify risks before they harm the project and to implement the necessary measures as soon as possible. Moreover, this method is also widely used in the literature [15-18]. FMEA is a method that adopts systematic solutions to identify potential problems in projects focuses on factor problems and solves problems according to the importance of the factor [19]. FMEA method ensures the quality of the projects in which it is applied, the priority order of the work items, the prevention of mistakes, and the determination of the risks and their effects. For these purposes, 3 basic elements are taken into consideration: probability of occurrence of failure (Table 1), severity of failure (Table 2) and detectability of failure (Table 3) in order to determine the priorities of risks and failures in projects [16, 17, 20, 21].

Table 1. Occurrence probability of risk (O) [16, 20,21]

Occurrence level of failure	Failure occurrence level	Frequency rating
Very high-inevitable	½ or more than	ten
	1/3	nine
High-recurring failure	1/8	eight
	1/20	seven
Medium-rarely failure	1/80	six
	1/400	five
Low-relatively low failure	1/2000	four
	1/15000	three
Very low-less likely failure	1/150000	two
	1/150000 or less	one

Table 2. Risk Severity classification (S) [16]

Effect	Effect of weight-severity	Severity rating
High level hazard coming without notice	It is the type of sudden failure that has a catastrophic effect	ten
Hazard coming without notice	It is a type of failure that comes on suddenly with a high damaging effect.	nine
Very high	It is the type of failure with a devastating impact that causes a project to suffer too much and to a high degree.	eight
High	It is the type of failure that causes too much damage to the equipment.	seven
Medium	It is the type of failure that affects the operation of the system and the applicability of the project.	six
Low	It is the type of failure that causes minor negativities in the project.	five
Very low	It is the type of failure that causes slight damage to the system.	four
Small	It is the type of failure that slows down the implementation of the system.	three
Very small	It is the type of failure that will cause confusion in the realization of the project.	two
No effect	It is the type of failure that has no effect in the application	one

In the planned project, it is necessary to determine the Risk Priority Number (RPN) coefficient for each of the risks that are determined to occur (Table 4). This coefficient is calculated as shown in Eq. (1) with the failure and risk occurrence probability, severity and detectability parameters [15, 16, 17, 20, 21].

$$\text{RPN} = \text{Occurrence (O)} \times \text{Severity (S)} \times \text{Detectability (D)} \quad (1)$$

Table 3. Detectability (discoverability) stages (D) [16]

Detectability	Probability of detectability	Rating
Imperceptible	It is not possible to determine the cause of the risk and the failure that follows the risk.	ten
Very far	It is not possible to determine the cause of the risk and it is too far away.	nine
Far	The determination of the cause of the risk is far away.	eight
Very low	Detection of the cause of risk is very low.	seven
Low	Detection of the cause of risk is low.	six
Medium	Determination of the potential cause of failure is medium	five
Above medium	Determination of the potential cause of failure is above medium	four
High	Determination of the potential cause of failure is high	three
Very high	Determination of the potential cause of failure is very high	two
Nearly sure	Determination of the potential cause of failure is nearly sure	one

Table 4. Risk priority number (RPN) and precautions [16]

Risk priority number (RPN)	Precaution and prevention
RPN<40	Low risk- There is no need for prevention
40≤ RPN≤100	Medium risk- prevention may be taken
RPN>100	High risk- prevention must be taken

RPN is a helpful factor in determining which of the failures and risks that may be encountered in projects should be resolved first. However, it is an important guide in taking precautions for failures and risks in projects. Pareto, another of the applied analysis methods, shows the priority status and importance of failures and risks, depending on the threshold values of the failures and risks detected. In this analysis, the general rate is 20% risk number and 80% limit value = 100%. However, these values can be 30% risk number and 70% limit value = 100%, 40% risk number and 60% limit value = 100% depending on the nature of the risks in the project and the type of the project [22]. The meaning of these values is that 20% of the number of risks constitutes 80% of the total risks in the project or 40% of the number of risks constitutes 60% of the total risks in the project. The important point here is that the sum of these two ratios gives the ratio of 100. For example, if the 80% limit value of 10 risks occurs in the first 2 risks, this ratio is expressed as 20% risk number and 80% limit value = 100% ratio. In the study, it was first decided which of these ratios would be appropriate depending on the type of project and risks, and then the analysis made at these ratios was considered as the first alternative (20%-80%=100%, 30%-70%=100%, 40%-60%=100%). The main purpose of Pareto analysis is to represent the vast majority of problems with a small number of risk factors. With this method, it is aimed to take measures at low cost for a few risks that are important in the projects and also make up a large percentage of the problems in the whole project. In addition, it is aimed that the progress of the project is not damaged. AHP, on the other hand, ensures the practitioners to consider all possibilities together with all factors and perform pairwise comparison of probabilities under relative priorities [23]. AHP is an easy to use and straightforward method and it is a highly preferred method by decision makers because takes into account the user subjective criteria in multi-criteria decision analysis (MCDA) [24-26]. The most common problem encountered in MCDA applications is to be able to determine the superiority, importance or weight in order to be able to select the factor by considering more than one option among different options. In the solution of this problem, AHP, which can be used effectively, is preferred because it is a mathematical method in decision making that handles all variables together by considering the priorities of both the individual and the group. AHP starts with determining the comparative decision making and preference matrix. In order to make a pairwise comparison, a pairwise comparison matrix is created using the AHP evaluation scale (Table 5) as suggested by [27] and [28]. When creating a pairwise comparison matrix, it should be answered which one of the criteria pairs takes precedence over the other and what should be the importance of this priority criterion than the other.

Table 5. AHP evaluation scale [27, 28]

Importance degree	Description
1	Equally important
3	1st criterion slightly more important than 2nd
5	1st criterion moderately more important than 2nd
7	1st criterion much more important than 2nd
9	1st criterion is absolutely more important than 2nd
2,4,6,8	Intermediate values are used in cases that require agreement

The next step after the creation of comparison matrix is to calculate the weights of the criteria, spite that AHP has a consistent systematic in itself, the results will be based on the consistency that emerges as a result of comparing the existing criteria with each other by the practitioners, hence, after the weight calculation of the criteria, the Consistency ratio (CR), which means likelihood in a randomly generated matrix gradation, needs to be calculated [29]. [30] suggests the rate of 10% as a maximum consistency rate. If a value found is above this value the pairwise comparison matrix should be reconstructed [31]. The consistency rate is calculated by the formula of Eq. (2) depending on the random index value (RI) and consistency index value (CI) (Eq. (3)).

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

$$CI=\frac{(\lambda-n)}{(n-1)} \tag{3}$$

Here λ is consistency vector mean and n is number of criteria.

3. Results and Discussion

Depending on the location of the area where the SPP installation is planned, parameters such as solar radiation, weather conditions, annual insolation, temperature, rainfall, snow and fog are among the most important criteria, because these parameters directly affect the amount and sustainability of the energy to be obtained from the power plant to be established. In this context, up-to-date, detailed and precise maps, plans and sections of the land where the project will be located should be prepared in the SPP installation. In addition, it is necessary to prepare 3 dimensional digital elevation models. For these reasons, it is also important to prepare simulations according to the slope and the aspect direction of the land where the SPP installation is planned. In the first phase of this work, in order to pre-define the negative situations that may arise from the risks that may occur while the plan-project phase is carried out for the purpose of SPP installation. In the first stage of this study, the risks that may occur in SPP installation projects were defined. For this purpose, the opinions of experts (mapping / geodesy and photogrammetry / geomatics, geology, construction, geophysics, machinery, industrial engineers, etc.) expressed in the literature and researches were also taken into consideration and the failures and risks encountered at this stage were investigated. Ten risks (Process No: A1-A10) detected as a result of the research were examined in FMEA systematic. In the second stage, as in the determination of failures and risks, likewise, taking into account the suggestions and ideas of experts on SPP installation, the probability of occurrence of these failures and risks (Table 1), their severity (Table 2) and their detectability (discoverability) (Table 3) were discussed together and RPN has been determined. Later, using Table 4, the risk group belonging to the risk was determined. RPN numbers were re-evaluated, taking into account the measures to be implemented in order to prevent the occurrence of failures and risks whose probability of occurrence was determined. With the implementation of the precautions, it was observed that these failures and risks were included in the low risk group (Table 6).

Table 6. Determination of failures and risks encountered during the project of SPPs with FMEA form

DETERMINATION OF FAILURES AND RISKS ENCOUNTERED DURING THE PROJECTING OF SOLAR POWER PLANTS
---FMEA FORM---

RPL=OCCURRANCExSEVERITYxDETECTIBILITY

OCCURRANCE	SEVERITY	DETECTIBILITY	RPN VALUE (Risk Priority Number)
1-2 Very Low	1-2 No effect or slightly	1. Sure 2.Very High	RPL<40 No need to take precaution LOW RISK
3-4 Low	3-4 Slightly	3. High 4. Above Average	40≤ RPL ≤100 Caution can be taken MEDIUM RISK
5-6 medium	5-6 Medium	5. Medium 6.Low Level	RPL >100 Caution must be taken. HIGH RISK
7-8 High	7-8 Serious	7. Very Low 8. Little	
9-10 Very High	9-10 Very serious	9.Very Little 10. Undetectible	

Process No	POTENTIAL CAUSES OF FAILURE		RISK EVALUATION					PRECAUTION ACTIVITY	RESPONSIBILITY	RISK EVALUATION				
	Failure	Reference	Occurrance	Severity	Detectibility	R.P.N	Importance			Occurrance	Severity	Detectibility	R.P.N	Importance
A.1	Failures and risks in solar radiation measurement and determination of weather conditions according to the location of the region	Regulations for wind and solar measurements for wind and solar energy license applications Regulations on meteorological data assessment.	5	7	5	175	HIGH RISK	The solar radiation coming to the land where the solar power plant will be installed should be calculated very well, taking into account the long years and atmospheric conditions. In addition, daily, weekly, monthly and annual periodic controls should be made and the effects of atmospheric effects such as temperature, precipitation and humidity on the power plant should be examined.	Meteorology Engineers	2	3	1	6	LOW RISK
A.2	Failures and risks arising from the lack of maps of the land to be installed or the lack and inaccuracies in the maps (topographic, settlement, vegetation, geology, etc.)	Large Scale Map and Map Information Production Regulation	7	9	5	315	HIGH RISK	In the field where the solar power plant will be established, the errors and deficiencies that will occur in the topographic maps should be corrected and completed by using terrestrial, aerial photography (photogrammetry) or remote sensing systems. These measurements should be adapted to Geographical Information systems and the map data including many data should be evaluated as a whole by using merging analysis. If the topographic measurements are outside the error limits, these measurements should be checked in the field and repeated.	Surveying / Geodesy and Photogrammetry / Geomatics Engineers	2	3	2	12	LOW RISK
A.3	Failures and risks made in the slope and aspect calculation of the land where the solar power plant will be built	Large Scale Map and Map Information Production Regulation	6	6	5	180	HIGH RISK	Topographic measurements should be checked on the field where solar power plant will be built and renewed if necessary. In addition, 3D digital elevation models of the field should be created and slope calculations should be made again on these models. If necessary, these analyzes and controls should be provided with geographic information systems.	Surveying / Geodesy and Photogrammetry / Geomatics Engineers and Geology Engineers	2	3	3	18	LOW RISK
A.4	Failures and risks made in explaining the geological structure of the land where the solar power plant will be installed	Regulations regarding geological maps, geology and geophysical studies.	6	9	5	270	HIGH RISK	The stratigraphic, lithological, geological features and discontinuity environment of the area where the solar power plant will be installed and its surroundings should be explained. However, map and section drawings should be made, well or drilling studies should be applied using geophysical methods, as well as ground and underground conditions should be explained.	Geology and Geophysics Engineers	2	3	2	12	LOW RISK
A.5	Lack, failures and risks in the geotechnical and static analysis of the land where the solar power plant will be installed	Regulations regarding geological maps, geology and geophysical studies.	6	9	7	378	HIGH RISK	According to the laboratory test results, the soil and soil structure properties, the chemical structure of the soil and the groundwater level should be determined. In addition, the solar panel construction and inverter weight that is planned to be used in the power plant area should be determined. Again, calculations should be made to prevent the solar panels from falling against the wind and the weight of snow. However, the chemical properties of concrete must be determined for the foundation.	Geology, Geophysics and Mechanical Engineers	4	3	3	36	LOW RISK
A.6	Failures and risks in the detection and measurement of the existing and potential landslides of the land where the solar power plant will be installed	Large Scale Map and Map Information Production Regulation	6	9	6	324	HIGH RISK	Periodic GPS and leveling studies should be carried out in the field where the solar power plant will be established. In addition, deformation and displacement (unit displacement, elongation, shortening, curvature, etc.) movements in horizontal and vertical directions should be determined. Topographic measurements in the field should be made with millimeter precision. In addition, deformation vectors in the field should be determined. Again, maps that reflect the topographical features of the region should be produced. In addition, the geological and topographical sections of the region should be examined and detailed field studies should be done. As a result, if there is no possibility of landslides in the field, planning studies of the solar power plant project should be done.	Geology, Geophysics Engineers, Surveying / Geodesy and Photogrammetry / Geomatics Engineers	3	3	3	27	LOW RISK
A.7	Failures and risks made in the drainage system of the land where a solar power plant will be installed	Regulations on meteorological data assessment. Large Scale Map and Map Information Production Regulation	5	6	4	120	HIGH RISK	The adequacy of environmental drainage should be checked, and the risk of flooding due to precipitation should be calculated. In addition, if the land does not have a risk in terms of flood / overflow potential, solar power plant project planning studies should be carried out.	Geology, Geophysics and Mechanical Engineers	3	3	2	18	LOW RISK
A.8	Failures and risks in cadastral and ownership / expropriation measurements of the land where solar power plant will be installed	Large Scale Map and Map Information Production Regulation Laws and regulations regarding expropriation	5	7	4	140	HIGH RISK	If there are deficiencies in terms of cadastral work in the area where the solar power plant will be established, the necessary topographic measurement and observation studies should be carried out.The studies can be carried out by geodetic, photogrammetric and remote sensing systems, as well as by digitizing the existing and reliable sheets.	Surveying / Geodesy and Photogrammetry / Geomatics Engineers	2	3	2	12	LOW RISK
A.9	Failures and risks in calculating the distance of the system to be installed to the distribution lines and centre	Large Scale Map and Map Information Production Regulation Technical and administrative specifications of the project and related regulations	4	7	4	112	HIGH RISK	Analysis techniques and planning such as geographic information systems based network analysis, proximity analysis and location analysis should be used in the areas where a solar power plant is planned to be built. Analysis accuracy should be further increased by using accurate, up-to-date and sensitive database information in accordance with these analyzes.	Surveying / Geodesy and Photogrammetry / Geomatics Engineers	2	3	4	24	LOW RISK
A.10	Failures and risks arising from delays in obtaining permits	Regulation on Solar Energy Based Electricity Generation Plants, Regulation on Technical Evaluation of Applications, Regulations of the relevant Public Institutions	5	7	3	105	HIGH RISK	Regarding the solar power plant project, establishment permits must be obtained from the relevant public institutions and organizations.In addition, the project for this power plant should be prepared and approved. However, after the establishment, it must be accepted by official institutions.	Project Management Engineers	2	2	2	8	LOW RISK

In the third stage of the study, Pareto Analysis systematic was applied in order to determine the order of importance and priority of the identified failures and risks. Two alternatives are considered in the study and the first alternative is 40% Risk Number and 60% Threshold Value=100% Ratio. The second alternative is at which risk the 80% Threshold Value is obtained in the Project. In the applied Pareto analysis, the first alternative, 40% Risk Number and 60% Threshold Value=100% ratio was chosen. This ratio was chosen from the rates of 20%-80%=100%, 30%-70%=100%, 40%-60%=100% (It is important that the total is 100%.). In addition, while choosing this ratio, the number of RPNs and cumulative risk values in the project was also taken into account. According to the Pareto Analysis applied, when the ratios (40%-60%=100%) are considered first, it is seen that the risks of A5, A6, A2, A4 come to the fore during the design phase of SSP projects. With this alternative, it can be commented that 40% of the risks determined during the design phase of SSP projects constitute 60% of all problems in the project. (Table 7, Fig. 1). When these risks are analyzed in a second Pareto analysis according to this threshold ratio, it is seen that A5, A6 risks come to the fore. (Table 8, Fig. 2). In the second alternative in the study, according to the rule of 20%-80%=100%, the issue of which risk threshold value of 80% corresponds to the number of risks in the projecting and design stage of project was investigated. In the ratios of 20% Risk Number and 80% threshold value = 100%, 80% threshold value ratio is taken into consideration. Accordingly, in the second alternative research, it was seen that the 80% limit value in the project coincided with the first 6 risk numbers. Accordingly, A5, A6, A2, A4, A3, A1 risks are on the forefront of the SPP project during the design phase for this threshold value (Table 7, Fig. 1). With this alternative, it can be interpreted that 60% of the risks identified during the SPP installation phase constitute 80% of all the problems in the project. When these risks are analyzed in a second Pareto analysis according to this threshold ratio, it is seen that A5, A6, A2, A4 risks come to the fore (Table 9, Fig. 3).

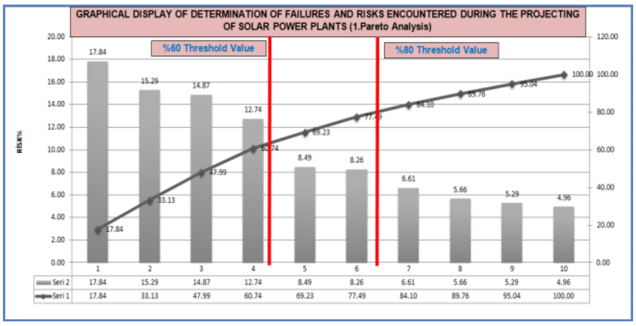

Figure 1. Graphic display of possible risks in the project of SPPs in Pareto system ((first alternative 40% Risk number and 60% limit value=100% ratio) and (second alternative 80% limit value obtained risk number))

Table 7. Examining the possible risks to occur in the SPP project in the 1st stage Pareto systematic ((first alternative 40% risk number and 60% limit value=100% ratio) and (second alternative risk number where 80% limit value is obtained) together)

DETERMINATION OF FAILURES AND RISKS ENCOUNTERED DURING THE PROJECTING OF SOLAR POWER PLANTS (1.PARETO ANALYSIS)

SEQUENCE NO	FAILURE MODE	PROCESS NO	RPN VALUE	RISK(%)	CUMULATIVE RISK %	RISK STATE
1	Lack, Failures and risks in the geotechnical and static analysis of the land where the solar power plant will be installed	A5	378	17.84	17.84	HIGH RISK
2	Failures and risks in the detection and measurement of the existing and potential landslides of the land where the solar power plant will be installed	A6	324	15.29	33.13	HIGH RISK
3	Failures and risks arising from the lack of maps of the land to be installed or the lack and inaccuracies in the maps (topographic, settlement, vegetation, geology, etc.)	A2	315	14.87	47.99	HIGH RISK
4	Failures and risks made in explaining the geological structure of the land where the solar power plant will be installed	A4	270	12.74	60.74	HIGH RISK
%60 Threshold Value						
5	Failures and risks made in the slope and aspect calculation of the land where the solar power plant will be built	A3	180	8.49	69.23	HIGH RISK
6	Failures and risks in solar radiation measurement and determination of weather conditions according to the location of the region	A1	175	8.26	77.49	HIGH RISK
%80 Threshold Value						
7	Failures and risks in cadastral and ownership / expropriation measurements of the land where solar power plant will be installed	A8	140	6.61	84.10	HIGH RISK
8	Failures and risks made in the drainage system of the land where a solar power plant will be installed	A7	120	5.66	89.76	HIGH RISK
9	Failures and risks in calculating the distance of the system to be installed to the distribution lines and centre	A9	112	5.29	95.04	HIGH RISK
10	Failures and risks arising from delays in obtaining permits	A10	105	4.96	100.00	HIGH RISK

Table 8. Determination of failures and risks encountered during the project of SPPs with 2.Pareto analysis with 60% threshold Value

DETERMINATION OF FAILURES AND RISKS ENCOUNTERED DURING THE PROJECTING OF SOLAR POWER PLANTS (2.PARETO ANALYSIS) (60% THRESHOLD VALUE)

SEQUENCE NO	FAILURE MODE	PROCESS NO	RPN VALUE	RISK(%)	CUMULATIVE RISK %	RISK STATE
1	Lack, Failures and risks in the geotechnical and static analysis of the land where the solar power plant will be installed	A5	378	29.37	29.37	HIGH RISK
2	Failures and risks in the detection and measurement of the existing and potential landslides of the land where the solar power plant will be installed	A6	324	25.17	54.55	HIGH RISK
%60 Threshold Value						
3	Failures and risks arising from the lack of maps of the land to be installed or the lack and inaccuracies in the maps (topographic, settlement, vegetation, geology, etc.)	A2	315	24.48	79.02	HIGH RISK
4	Failures and risks made in explaining the geological structure of the land where the solar power plant will be installed	A4	270	20.98	100.00	HIGH RISK

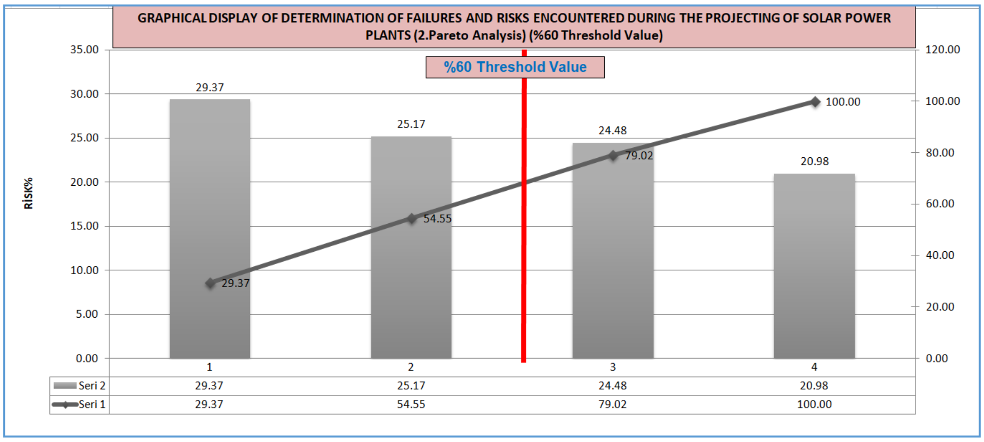

Figure 2. Graphical display of determination of failures and risks encountered during the project of SPPs with 2.Pareto analysis with 60% threshold value.

Table 9. Determination of failures and risks encountered during the project of SPPs with 2.Pareto analysis with 80% threshold value

DETERMINATION OF FAILURES AND RISKS ENCOUNTERED DURING THE PROJECTING OF SOLAR POWER PLANTS (2.PARETO ANALYSIS) (80% THRESHOLD VALUE)

SEQUENCE NO	FAILURE MODE	PROCESS NO	RPN VALUE	RISK(%)	CUMULATIVE RISK %	RISK STATE
1	Lack, Failures and risks in the geotechnical and static analysis of the land where the solar power plant will be installed	A5	378	23.02	23.02	HIGH RISK
2	Failures and risks in the detection and measurement of the existing and potential landslides of the land where the solar power plant will be installed	A6	324	19.73	42.75	HIGH RISK
3	Failures and risks arising from the lack of maps of the land to be installed or the lack and inaccuracies in the maps (topographic, settlement, vegetation, geology, etc.)	A2	315	19.18	61.94	HIGH RISK
4	Failures and risks made in explaining the geological structure of the land where the solar power plant will be installed	A4	270	16.44	78.38	HIGH RISK
%80 Threshold Value						
5	Failures and risks made in the slope and aspect calculation of the land where the solar power plant will be built	A3	180	10.96	89.34	HIGH RISK
6	Failures and risks in solar radiation measurement and determination of weather conditions according to the location of the region	A1	175	10.66	100.00	HIGH RISK

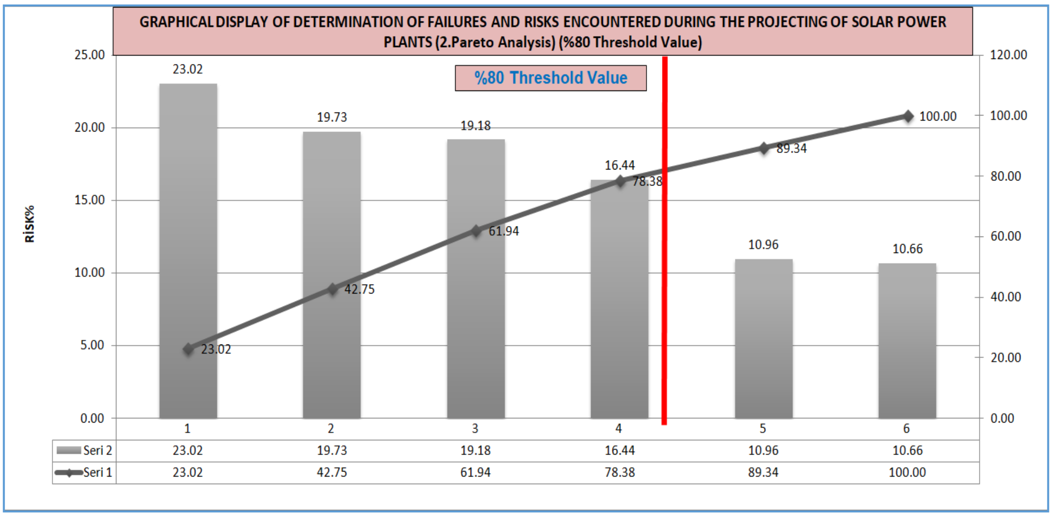

Figure 3. Graphical display of determination of failures and risks encountered during the project of SPPs with 2.Pareto analysis with 80% threshold value.

In the fourth stage of the study, the weight of each risk criterion was calculated with the comparison matrix created using AHP for the risks that occur in the plan-project phase of SPP installation. The pairwise comparison matrix is shown in Table 10, and the resulting weight matrix is shown in Table 11. The factors with the highest weight obtained from the comparison matrix were determined as A5, A6, A2, A4, A1, A3, A8, A7, A9, A10, respectively.

Table 10. Pairwise comparison matrix

Parameters	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
A1	1	1/5	3	1/2	1/9	1/7	3	3	2	2
A2		1	3	2	1/2	1	7	5	7	7
A3			1	1/3	1/5	1/5	3	2	3	3
A4				1	1/3	1/3	5	3	5	5
A5					1	3	7	5	7	7
A6						1	5	3	5	5
A7							1	1/2	2	2
A8								1	2	2
A9									1	1
A10										1

Table 11. Weight matrix

Parameters	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	Weight
A1	0.04	0.03	0.14	0.04	0.03	0.02	0.09	0.13	0.06	0.06	0.06
A2	0.19	0.18	0.14	0.19	0.16	0.15	0.21	0.21	0.20	0.20	0.18
A3	0.01	0.06	0.05	0.03	0.06	0.03	0.09	0.09	0.08	0.08	0.06
A4	0.08	0.09	0.14	0.09	0.11	0.05	0.15	0.13	0.14	0.14	0.11
A5	0.35	0.35	0.23	0.28	0.32	0.46	0.21	0.21	0.20	0.20	0.28
A6	0.27	0.18	0.23	0.28	0.11	0.15	0.15	0.13	0.14	0.14	0.18
A7	0.01	0.02	0.01	0.02	0.05	0.03	0.03	0.02	0.06	0.06	0.03
A8	0.01	0.03	0.02	0.03	0.06	0.05	0.06	0.04	0.06	0.06	0.04
A9	0.02	0.03	0.02	0.02	0.05	0.03	0.01	0.02	0.03	0.03	0.03
A10	0.02	0.03	0.02	0.02	0.05	0.03	0.01	0.02	0.03	0.03	0.03
Sum of Weights	1	1	1	1	1	1	1	1	1	1	1

The "Consistency ratio" (CR) has been calculated as 0.06 which was determined in order to detect the values in the comparison matrix created and the obtained weights are consistent or not. Since the ratio obtained is below 0.10 suggested by [30], it has been concluded that the values found as a result of the pairwise comparison matrix are consistent with each other.

4. Conclusion and Suggestions

In the planning and projecting phase of SPP projects, it is an important issue to determine the location, geometry and geological and geophysical conditions of the land where the SPP facility to be installed. In these projects, in the process of creating maps, sections and geological sections, field observations and studies, drilling activities, engineering measurements and evaluating all these studies together with previous studies are very important. In this study, failures and risks that may occur during the implementation of the plan-project stage, which is the first stage of SPP installation, have been investigated in FMEA Pareto and AHP systematic. In addition, the measures to be taken against these failures and risks have been determined by taking into account the opinions of experts in the literature and researches. As a result of the review of the FMEA systematic analysis, failures and risks in the high risk group and the precautions of the said were determined and afterwards, Pareto analysis was performed. In the first alternative Pareto analysis, it was determined that 4 failures and risks with process numbers A5, A6, A2 and A4 are important, depending on the 60% threshold value (40% Risk Number and 60% Threshold Value=100% ratio). This ratio was chosen from the rates of 20%-80%=100%, 30%-70%=100%, 40%-60%=100%. (It is important that the total is 100%). When the second Pareto analysis made in this first alternative group, it was observed that the risks A5 and A6 came to the fore according to 60% threshold value. In the second alternative in the study, according to the rule of 20%-80%=100%, the issue of which risk threshold value of 80% corresponds to the number of risks in the project was investigated. In the ratios of 20% Risk Number and 80% Threshold Value = 100%, 80% threshold value ratio is taken into consideration. When the examination is made depending on the 80% threshold value in the Pareto analysis, it has been revealed that 6 failures and risks with process numbers A5, A6, A2, A4, A3 and A1 need to be taken into consideration more while working on the plan-project phase of SPP installation. After that, in the second Pareto analysis made in this second alternative group, it was observed that the risks with numbers A5, A6, A2, A4 and A3 came to the fore according to 80% threshold value. For SPP projects, Pareto analysis was applied twice in both alternatives. In the project phase, it is aimed to find as few risks as possible, which constitute the majority of the problem. In addition, in the progress of SPP projects, a small number of risks have been identified, making it possible to solve most of the problems in the project.

As a result of the analysis made with AHP, it was revealed that there are 4 failures and risks with process numbers A5, A6, A2 and A4, and more attention should be paid to the plan-project phase of the SPP installation. The failures and risks that may occur during the planning-project phase of the SPP installation have been analyzed using FMEA, Pareto and AHP methods, taking into account the opinions of the relevant experts in the literature and researches. When the results are compared, the requirement to consider failures and risks with process numbers A5, A6, A2 and A4 in all 3 methods is highly recommended. Among these risks, it has been determined that the risks A5 and A6 are more important. This situation reveals that the results of the analysis applications are quite compatible with each other. The methods applied in the study are very important in terms of producing results that are compatible with each other and showing the reliability of the opinions of experts in the literature and researches. With this work carried out, contribution was made to the creation of risk criteria with minimum level that should be included in the SPP standard risk analysis review lists, moreover, it is emphasized that FMEA, Pareto analysis and AHP methods are very powerful methods in performing risk analysis of SPP installation.

Contributions of the Authors

All authors contributed equally to the study.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

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