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Hybrid Framework of, EWGM-FMEA, Analytical Hierarchy Process and Risk Balance Score Card for Risks Assessment in Energy Sector

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Abstract: Power plants are very important for continuous electricity energy supply and have been affected by many disruptions. Furthermore, the power grid is a critical item for both economy and society. Accordingly, the aim of this paper is to adopt a risk assessment tool combining an improved Failure Mode and Effect Analysis (FMEA), Analytical Hierarchy Process (AHP) and enhanced Risk Balance Score Card (RBSC) to model nine risk categories in the energy sector. The outputs of the improved FMEA methodology will be utilised as the inputs for the BSC-AHP framework. The improved FMEA methodology combines the exponential and weighted geometric mean to overcome some drawbacks of the conventional FMEA. The approach helps the top management in prioritising 84 risk indicators particularly, in power plants. The results of this model elucidate that the highest priority (most risky perspective) is for the supply chain perspective with 24.2% of the influence, followed by the internal and operational business process perspective with 18.4%. In this perspective, the technical risk is the key risk with 10.4% followed by the disruption risk with 9.4% while the lowest priority risk in this perspective is the project neglect risk with 2.5%. The sustainability perspective coming as the third priority perspective with 17.7%, where the environmental and safety health category covers about 41.7%, followed by the technological pillar with 35.5% and the social pillar with 22.8%. At the fourth level, the customer/demand perspective is coming with 14%, where the load forecasting risk has the highest priority in this perspective with 49%. The learning and growth perspective stay at the fifth level with 13% where the human resources risks category has more influence than the management risks category. The lowest risk perspective priority is the economic perspective with 12.7%. These results will help the top management in taking a holistic view of various non-technical risks at the strategic level and the priority for each one then, the suitable decision can be taken. The significance of this research is in presenting a novel improved for the traditional FMEA and combining it with the BSC-AHP methods to improve the risk assessment process of 84 risks of six perspectives of BSC in power plants at the strategic level.

Keywords: Exponential Weighed Geometric Mean (EWGM), FMEA, RPN, AHP and BSC

1. Introduction

The energy sector has been facing risks associated with economic, social, environmental, technological and a wide group of risks through the supply chain. Significant adverse effects in the energy sector in short-term and long-term will result from these risks and disruptions [1]. According to Afgan et al [2], a fluctuation in the oil price has a major influence of sourcing and distribution strategy decisions, where the fuel accounts for around (1/4) to (1/3) of transport operating costs, therefore, any variation in the oil price has a direct impact on the supply costs of shippers. Moreover, Gonzalez (Gonzalez, 2015) illustrates that the effects of liberalisation process of energy markets industry are considerable; the competitive of the energy market is increased, which also changed the stochastic pricing energy approach. Furthermore, the energy market players have encountered the increasing risk level, therefore; the movements of the market will consider the keystone for the market player's decision-making process for managing controllable risks (market risk, credit risk, and operational risk) or for uncontrollable risks like the weather; which affect production and demand. Thus, powerful operational and planning decisions additionally, appropriate risk management strategies should be adopted and taken by the energy market players. Due to that, the development of risk model of electricity chain is an important need, to predict, address and manage these risks.

An improved FMEA methodology has been used to identify nine risk categories including a proper 84 Risk Indicators (RI's) within all these categories through the Lifecycle stages of power plants (explained in our conference papers). This methodology improves the traditional FMEA and overcomes some of the related drawbacks by combining the exponential and weighted geometric mean by considering the weights for the three risk factors (severity, occurrence and detection) through utilising the AHP. The results of this improved methodology demonstrate that the duplication number of Risk Priority Number (RPN) have been decreased additionally, the results are more reasonable and depend on the three risk factors not just on the severity value. Afterwards, the outputs from the EWGM-FMEA methodology have been used as the inputs of the BSC-AHP to develop the related matrices accordingly, risks can be prioritised and weighted then, the most prominent risk indicator on power plants can be addressed.

This paper aims to establish a framework that combines the BSC-AHP tools with an improved FMEA to develop a framework to prioritise the risks in power plants. Therefore, the objectives of this research are to:

1. Identifying and understanding various types of risks (6 risks perspectives with 9 categories) in the energy sector;
2. Developing a risks framework that combines BSC and AHP to assess risks in the energy sector;
3. AHP technique helps in weighing and prioritising these different types of risks and overcomes the BSC drawback where the BSC help in categorising 84 risks.

To derive the risk priority values; a pairwise comparison of various risks has been conducted using the Expert choice software. These priorities have been used to determine the ranking level of each risks perspective and each risk.

2. Literature Review

To improve the service of generating electricity and minimise the risks, an integral approach for identification of the existing and the potential risks of power plants should be handled. Chan (Chan, 2009) shows that the potential risks along the operation of the business can disrupt the operation and cause significant losses, either these risks are catastrophic events like fire or flood or other smaller events like failures and breakdowns. All these risks will cause revenue losses, dropped production rates, inability to meet planned production goals, and these lead to reduce the reliability and hit the reputation of the company. In the same context, Garbuzova-schlifter and Madlener [5] clarify that risks present in each stage of life cycle, from the planning stage to the decommissioning stage of power plants and risks in one stage may affect other stages due to the integrity in the supply chain.

Risks should be understood by the companies to generate a plan for manage it furthermore, it is crucial to identify and understand the risks for minor and major risks to determine which failure will cause risk profiles particularly, man-made risks. Interestingly, the report describes seven key areas should be focused on it [6].

Risk management is one of the most relevant approaches and systematic application of strategies, procedures and practices management that have been introduced to identifying and analysing risks which exist through the whole life of product or process. The risk management needs in energy sector emerge from the role of power plants which is very crucial for continuous and reliable energy supply [4]. Wu and Olson [7] display that enterprise risk management is part of the strategic planning process Furthermore, enterprise risk is incorporated across the corporate strategy of an enterprise Risks are present in all stages, from the commission phase to decommission. According to [8] risks in one stage may affect other stages due to the integrity of the supply chain. Organisations share price is impacted by 7% from a significant supply chain disruptions either these disruptions are natural disasters, production issues, shortage of parts, recalls etc. [9]. Therefore, it is important to identify risk factors in all stages: commissioning and starting; fuel supply and delivering; operating, running, maintenance and Ash disposal; and finally the decommission stage). Thus, it is important to develop a comprehensive, coherent, methodological, structured and systematic approach to identify and assess the risks. In order to that, the risk mitigation plans can be developed and implemented.

AHP is one of the most frequently Multi-Criteria Decision Making Process (MCDM) methods used to solve complicated problems in various research areas. This refers to many reasons. Firstly, the natures of AHP, where it can decompose the complex decision problem into a hierarchical structure and execute a pairwise comparison between the criteria of a hierarchy. Secondly, other MCDM methods need certain many data but AHP needs less intensive data and can be applied with limited data. Thirdly, AHP can use quantitative and/or qualitative criteria. Fourthly, the preferences in AHP are obtained for two criteria at the same time but for other scale rates just one criterion at a time. Finally, AHP is capable of capturing the subjectivity and the objectivity and gives reasonable results of the decision-making process [5].

The complexity and interdependency of energy sector either in critical infrastructure or in key resource for today's society and economy life. This study focuses on the accident risks where the accident risk assessment is considered as the component in a holistic evaluation of energy security aspects and sustainability performance and they conclude that the second largest group of all man-made accidents worldwide accidents are located in the energy sector [10].

In the same area, Samvedi, Jain and Chan [11] assert that the risks of several energy technologies of society and environment that may happen not only during the actual energy generation but also at all phases of energy chains.

To estimate the likelihood of many risk events that may happen, the organisations can depend on the historical data, moreover the managers can use another tools and frameworks if the historical data are not available or insufficient to quantify risk exposure. In addition to that, he clarifies that the heat map score is used by managers to determine the priorities for risks. The risk events that score 15 or higher are the most likely and consequential and the strategy map offers a powerful framework for strategic and operational risks identifications [12].

As Radivojević and Gajović [13] confirm that the data related to the risks are not available thus, scholars depend on the experience and intuition of experts. In the same context, Geng *et al* [6] clarify that allocating and setting proper indicators to evaluate and assess the business performance is very important needs moreover, they represent that these indicators will be changed due to the nature of business operating. Furthermore, their study has been explained the obstacles that lie ahead in building effective and efficient indicators and are summarised as:

1. There is no detailed explanation or standardised process on collection, calculation and submission of data;
2. The indicator system is a voluntary one and may be chased with differing intentions.

Through developing an effective KRI's it should ensure that collecting and aggregating data have been done through elaborating all parties. In addition to that, they emphasise that the quality of the available data used for monitoring risks is a crucial element of developing the KRI's. Sources of information can help in choosing the KRI's [14]. Moreover, the availability of data can provide enrich information about the potential future risks. Internal data is unavailable for many risks, particularly those that have not been suffered previously. External risks expected to have a significant impact such as economic conditions changing, interest rate fluctuations, or new regulations and legislation. Organisations depend on the external data to develop the related KRI's where are roots cause and intermediate events, which can affect strategies, may emerge from outside sources of the organisations.

Based on the aforementioned, 84 risk indicators have been identified as shown in Table 1. These can impact the supply chain of generating electricity.

Table 1. *Identified Risk Indicators.*

Risk Indicators
Economical Risks Perspective:
1. Competition Risk
2. Interest Rate Risk
3. Exchange Rate Risk
4. Supplier Price Risk (Risk of fuel price volatility)
5. Price of electricity Risk
6. Credit Risk
7. Investment Risk
8. Inflation risks
9. Debt collection risk
10. Operating revenue and expense risk
11. Procurement cost risk
12. Global Economic Recession risk
13. Asset Depreciation Risk
14. Market liquidity risk
Environmental and Safety Health Risks Pillar:
15. GHG emissions (NOx, Co_2 and So_2) risk
16. Environmental regulations
17. Industrial water reuse ratio risk (Reuse ratio of industrial water).
18. Recycling of treated water risk
19. The solid waste risk in thermal power plants
20. Waste handling risk (Polychlorinated Biphenyls (PCBs) Waste Management, chemical solid waste,…. etc.)
21. Lost time Injuries Risk
22. Accident fatalities per energy produced (Severe accidents Risks)
23. Human Toxicity Potential Expresses (ex. Polychlorinated Biphenyls (PCBs)in power plants in Jordan)
24. Noise Impact Caused by Energy System
25. Bad Odours Risk
26. Mortality due to normal operation (reduced life- expectancy Years of life lost/GWh)
27. Soil Pollution
Social Risks Pillar:
28. Lack of motivation for staff
29. Lack of innovation
30. Lack of organisational learning capability

Risk Indicators
31. The poor relationship between parties
32. Labour strikes risk
33. Social challenges (poverty, substantial levels of inequalities, as well as health and demographic challenge)
34. The behavioural aspect of employees
35. Union/ labour relations risk
36. Reputation Risk (Negative Media Coverage)
37. Changing behaviour risk (Change Human Behaviour, effective change management will likely provide a sustainable competitive advantage in the future)
38. Local community impacts risk
Technological Risks Pillar:
39. Obsolescence Risk (Adaptation or Technology Exchange risk
40. Improved fuel efficiency/efficiency of the combustion risk
Technological Risks Pillar:
41. Sustainable technology innovation risk/ energy efficient technologies or renewable methods
Customer/Demand Risks Perspective:
42. Policy & Regulation /system change risk
43. Load forecasting risk/Demand uncertainty
44. Risk of Coincidence problems with holidays
Supply Chain Risks Perspective:
45. Production risk (Supply risks Raw material and energy-generating product)
46. Disruption Risks (Malfeasance/ Sabotage risk, Accident or natural Disaster)
Internal and Operational Business Process Risks Perspective:
47. Technical risk (machine failure/ downtime)
48. Material or equipment quality risk
49. Risk of Failure to identify defects/Equipment Failure
50. The scarcity of resources risk (Shortage of materials and equipment)
51. Start-up cost risk
52. Operating cost risk
53. Raw material and product quality standards (fuel) risk
54. Disruption Risks (Malfeasance/ Sabotage risk, Accident or natural Disaster)
55. Risk of fuel management
56. Delay in the schedule (Maintenance Arrangement Risk)
57. Project activity neglect risk
58. Warehouse or IT Breakdown Risk
59. Software Failure Risk
60. Infrastructure security problems risk
Human Resources Risks:
61. Loss of key personnel risk
62. Poor Labor Productivity risk
63. Employee turnover risk
64. Performance incentive risk
65. Training risk
66. Performance measurement risk
67. Employee safety risk
68. Job seasonality (months/year) risk (level of continuity of the job over time)
69. Unemployment rate risk (Job creation risk or number of direct jobs created, the unemployment rate is used by policymakers to measure economic activities and social stability)
70. Sick leave risk ([h/year]) the number of hours which employees spend on sick leave per year
71. IT infrastructure risk (Scarcity of skills/technique (Lack of Qualified labour)
72. Moral hazard risk
73. Partnership (relationship) risk (Lack of relationship management)
74. Inappropriate organizational response to changing environment risk
75. Inappropriate organizational structure risk
76. Ineffective integrating and managing enterprise resources risk
77. Unclear strategy for achieving organizational objectives (Poor definition of scope) risk
78. Poor coordination
79. The mismatch between organizational strategy and culture
Human Resources Risks:
80. Information sharing problems
81. Planning risk
82. Location of facilities selection risk
83. Management lagging behind expansion
84. Interaction between stakeholders

3. Research Methodology

Various risks have been collected from the literature and own experience (as identified in table 1), an improved FMEA is used to identify the risks (explained in our conference paper), then the AHP has been applied to prioritise these risks depending on the output of the FMEA. The AHP is one of the MCDM processes that has been applied to synthesise expert judgments using the RPN values from the FMEA to show the effects of these risks on the performance of power plants. Based on the importance of each risk indicator, the comparison matrix will be generated afterwards, the priorities and the weights for all risks have been determined and categorised for three risk levels (High, medium and low-risk levels), Figure 1 represent these steps.

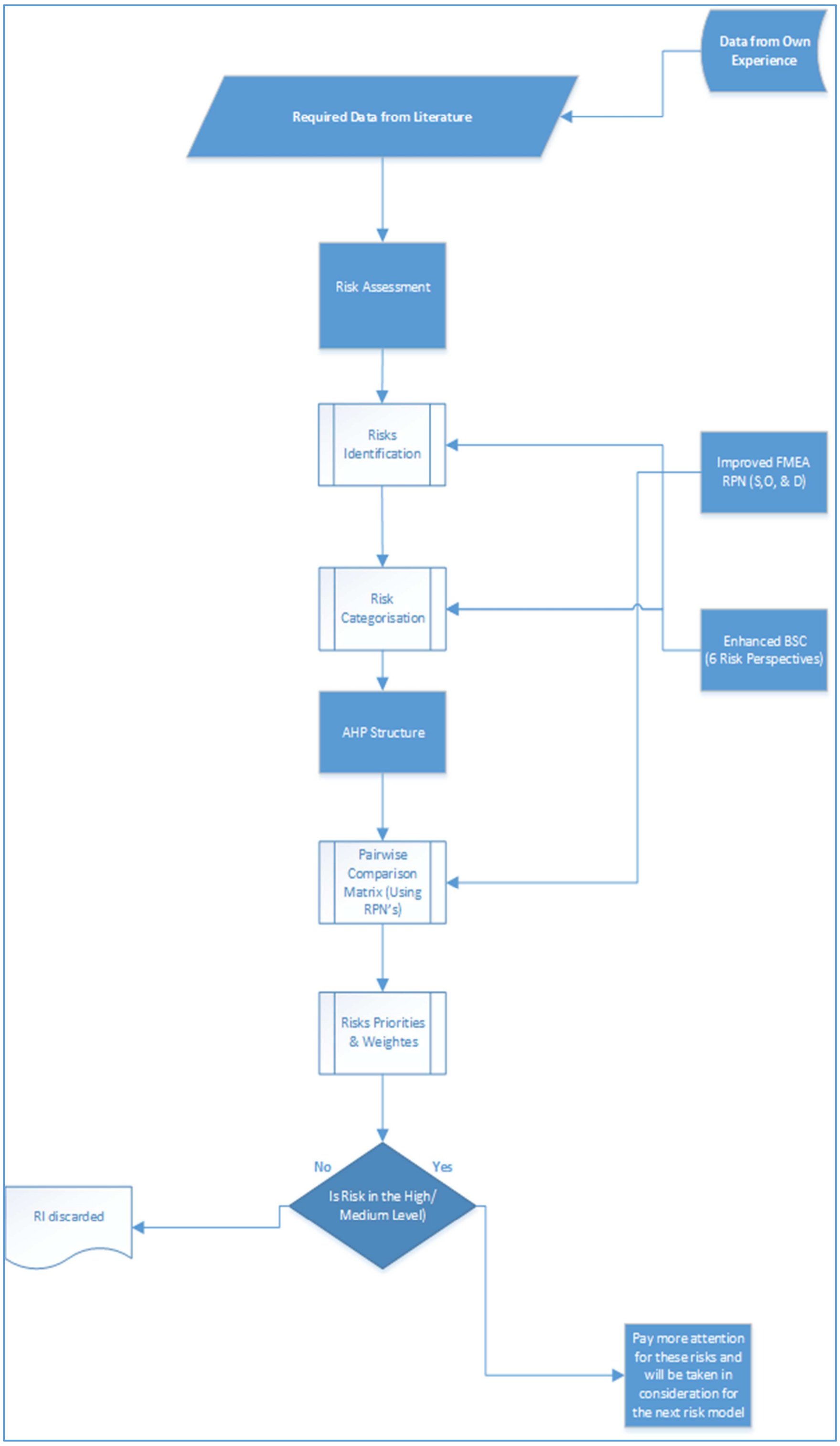

Figure 1. *Research Methodology Steps.*

The analytical hierarchy process is a multi-criteria decision framework that allows constructing the decision into Goal, criteria, sub-criteria and alternatives. Its aim is to categorise this decision framework in a hierarchy and logical consequence.

3.1. Modelling in AHP

Depending on Table 1, a part of the hierarchy structure has been built as presented in figure 2.

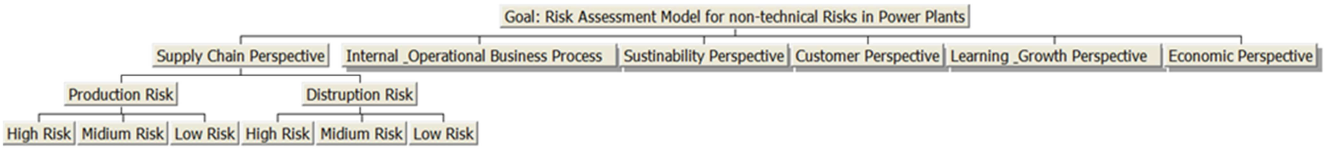

Figure 2. *AHP Structure of the Risk Model.*

The following process describes these hierarchy levels:

Level 0 Goal: Risk Assessment

Level 1 Main Criteria 1: Sustainability perspective:

Level 2 Sub-criterion 1.1: Environmental Pillar;

Level 3 Sub-Sub Criteria: 12 Risk Indicators (13 RI`s)

Level 3 Sub-criterion 1.2: Social Pillar;

Level 3 Sub-Sub Criteria: 12 Risk Indicators (11 RI`s)

Level 3 Sub-criterion 1.3: Technological Pillar (3 RI`s)

Level 1 Main Criteria 2: Economic perspective:

Level 2 Sub-criterion (14 RI`s)

Level 1 Main Criteria 3: Learning and growth perspective:

Level 2 Sub-criterion 3.1: Human Resources Risk; Level 3 Sub-Sub Criteria: 12 Risk Indicators (12 RI`s) Level 2 Sub-criterion 3.2: Management Risks Level 3 Sub-Sub Criteria: 12 Risk Indicators (12 RI`s)

Level 1 Main Criteria 4: Internal & operational business process perspective:

Level 2 Sub-criterion (14 RI`s)

Level 1 Main Criteria 5: Customer perspective:

Level 2 Sub-criterion (3 RI`s)

Level 1 Main Criteria 6: Supply chain perspective: Level 2 Sub-criterion (2 RI`s)

Level 4 Alternatives: Three Risk Levels (High, Medium and Low)

1. The matrix values and the importance of the elements have been assessed and evaluated according to the Saaty scale from 1 to 9 [16].
2. The global priorities have been calculated depend on the values of local priorities that have been obtained for each risk level.
3. The result is a relative importance of each element and has been ranked according to the weights of the risks. Depending on the relative importance of the risk perspectives, the impact on the overall risk level can be considered through three different alternatives (High, Medium and Low-risk levels).
4. Ranking of risk level indicates that the level of overall risk for the selected power plant chain and the risk indicators can be determined from the weighting of the priorities for each risk indicator.

The developed risk model will help the top management to take a wise strategic decision to reduce the overall risk where [11] demonstrate that a risk affecting the strategic level is much more risky than one affecting the operational level.

3.2. Pairwise Comparison

After the AHP structure has been developed, the pairwise comparison matrix for each sub-structure model is accomplished. The priorities of each risk perspective and each risk indicator have been calculated using the Expert Choice software. In the pairwise comparison matrix, a comparing between each risk indicator in pairs to represent the influence of each risk on the performance of power plants. There are two options for this pairwise comparison, one option compares the risk indicator with respect to the goal and the second option compare the risk indicator with respect to a specific risk perspective.

4. Research Findings

The pairwise comparisons matrix for each risk indicator within the related risk perspectives are determined, the weights for each perspective and each risk indicators have been illustrated in Table 2.

Table 2. *Summary of the Figure AHP weights for the Six Risk Perspectives.*

Risk Perspective	Perspective Priority	Risk Indicators	Category Priority	Sub-Risk Indicators	Priority
Supply Chain Perspective	0.242	Production Risk			0.500
		Disruption Risk			0.500
Internal & Operation Business Process	0.169	Technical Risk			0.104
		Disruption Risk			0.094
		Delay in Schedule			0.091
		Fuel Quality			0.091
		Operating Cost Risk			0.091
		Material or Equipment risk			0.076
		Risk of Fuel Management			0.074
		Risk of failure to identify defects			0.068

Risk Perspective	Perspective Priority	Risk Indicators	Category Priority	Sub-Risk Indicators	Priority
		Scarcity of Resources			0.068
		Start-up Cost			0.068
		Warehouse or IT Breakdown			0.056
		Infrastructure security problems risk			0.047
		Software Failure risk			0.047
		Project Activity Neglect risk			0.025
Sustainability Perspective	0.177	Environmental Risks	0.417	Environmental Risks	0.417
				Waste Handling Risk	0.095
				Noise Impact Risk	0.093
				GHG Emissions	0.093
				Lost Time Injuries Risk	0.091
				Bad Odours Risk	0.089
				Soil Pollution	0.086
				Solid Waste Risk	0.084
				Human Toxicity	0.081
				Industrial Water Reuse Risk	0.062
				Mortality Risk	0.059
				Accident Fatalities Risk	0.058
				Recycling of treated water Risk	0.058
				Environmental Regulations Risk	0.050
		Social Risks	0.228	Social Risks	0.228
				Labour Strike Risk	0.175
				Changing Behaviour Risk	0.126
				Union/Labour Relation Risk	0.119
				Social Challenges Risk	0.111
				Reputation Risk	0.022
		Technological Risks	0.355	Technological Risks	0.355
				Sustainable technology innovation risk	0.413
				Obsolescence Risk	0.298
				Improved Fuel Efficiency Risk	0.289
Customer Perspective	0.14	Load Forecasting Risk			0.49
		Policy & Regulation Risk			0.321
Learning & Growth Perspective	0.13	Human Resources Risks	0.517	Human Resources Risks	0.517
				Employees Safety Risk	0.145
				IT Infrastructure Risk	0.100
				Sick Leave Risk	0.095
				Employees Turn Over Risk	0.094
				Unemployment Rate Risk	0.094
				Training Risk	0.089
				Poor Labour Productivity Risk	0.059
		Management Risks	0.483	Management Risks	0.483
				Management Lagging Behind Expansion	0.099
				Mismatch Between Organisational	0.078
				Planning Risk	0.078
				Poor Coordination	0.072
Economic Perspective	0.172	Supplier Price Risk			0.154
		Price of Electricity Risk			0.149
		Asset Depreciation Risk			0.131
		Inflation Risk			0.088
		Global Economic Recession Risk			0.082
		Operating Revenue Risk			0.070
		Investment Risk			0.069
		Procurement Cost Risk			0.067
		Debt Collection Risk			0.044
		Interest Rate Risk			0.030
		Exchange Rate Risk			0.029
		Credit Risk			0.014

As shown in the priority table 2 and Figure 3; the highest priority (most risky perspective) is for the supply chain perspective, which includes two types of risks: (production risk and disruption risk) with 24.2% of the influence. Followed by the internal and operational business process perspective with 18.4% where the technical risk is the key risk in this perspective with 10.4% followed by the disruption risk with 9.4% and the lowest priority risk in this perspective is the project neglect risk with 2.5%.

The sustainability perspective coming as the third priority perspective with 17.7%, where the environmental and safety health category covers about 41.7%, followed by the technological pillar with 35.5% and the social pillar with 22.8%.

At the fourth level, the customer/demand perspective is coming with 14%, where the load forecasting risk has the highest priority in this perspective with 49%.

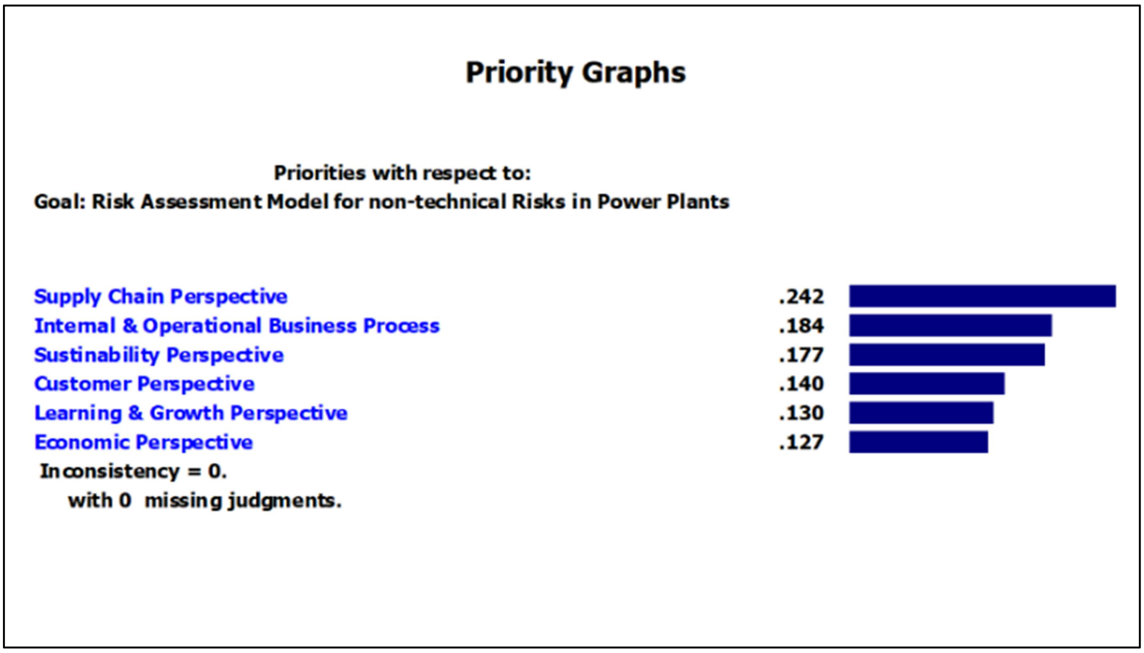

Figure 3. *BSC-AHP Risk Results.*

The learning and growth perspective stay at the fifth level with 13% where the human resources risks category has more influence than the management risks category. The lowest risk perspective priority is the economic perspective with 12.7%.

In summary, the priority for each perspective and the level of the risk either in high, medium or in the low level have been elucidated in Table 3.

As a whole, these results will be changed depending on power plant and the policy of the country. Therefore, the same FMEA methodology can be applied and different results can be generated.

Table 3. *The Priorities for Six Perspective and the level of Risk.*

Risk Perspectives	Traditional Method	Modified EWGMA	High-Risk Level	Medium Risk Level	Low-Risk Level
Economic Perspective	0.129	0.127	0.474	0.359	0.166
Sustainability Perspective	0.171	0.177	0.463	0.303	0.234
Social Risks	0.264	0.228	0.322	0.364	0.314
Environmental Risk	0.487	0.417	0.595	0.213	0.192
Technological Risks	0.249	0.350	0.399	0.369	0.232
Customer/ Demand Perspective	0.169	0.140	0.43	0.381	0.189
Internal and Operational Perspective	0.174	0.184	0.489	0.403	0.108
Supply Chain Perspective	0.236	0.242	0.766	0.191	0.043
Learning & Growth Perspective	0.121	0.130	0.382	0.469	0.149
Human Resources Risks	0.469	0.517	0.335	0.512	0.154
Management Risks	0.531	0.483	0.432	0.424	0.144

5. Conclusions

In this paper, a hybrid tool has been used to assess 84 risks in power plants. The BSC as a performance measurement tool has been enhanced and developed as a risk measurement tool with six perspectives rather than four and combined later with one of the MCDM to prioritise 84 risk indicators in power plants. These risks have been selected from literature and own experience. The comparison matrices have been conducted depending on the value of an improved FMEA RPN 's.

The developed models were applied for various 84 risks to determine the level of these risks either in the high, medium or low-level area afterwards, the Key risk indicators (KRI's) which have been located in the high and medium level area will be selected and the low-level risk will be discarded.

The results of this AHP model will be used to build the system dynamic model with nine sub-risk models. As shown, the most risk perspective is the supply chain perspective with 24.2% of the influence. Followed by the internal and operational business process perspective with 18.4%. Depending on the priorities of all risk indicators, the results show that the top management should pay attention to various types of risks either supply chain risks, internal and operational risks or sustainability risks. The developed risk model will help the top management to prioritising the risks and support their decision making process.

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