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Research Article

RANKING OF ENVIRONMENTAL POLLUTION FACTORS AND MANAGEMENT STRATEGIES IN POWER PLANTS USING MULTI-CRITERIA DECISION-MAKING (AHP, TOPSIS, SAW) MODELS CASE STUDY: SANANDAJ COMBINED CYCLE POWER PLANT

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ABSTRACT
Environmental pollution is one of the most serious problems that today's world is dealing with and if its increasing growth is not controlled, we would face environmental disasters. The oil and gas industries are the major sources of environmental pollutants. Human knowledge and experience emphasizes on the use of assessment methods and techniques before and during the onset of such activities. In particular, due to the integration of multiple factors and constraints and considering them in conjunction and making the right decision in the environment because of its high complexity, application of one of the various techniques of Multi-Criteria Decision-Making is common. The present study states that in some cases such as power plants, where pollutants act broader and more complex, the merely use of above-mentioned techniques is not sufficient and generally the results of such survey have espoused biased judgments. Hence, the present paper aims to rank environmental pollutants in power plants (case study: Sanadaj Combined Cycle Power Plant) and propose strategies using Multi-Criteria Decision-Making models. At first, previous studies and experiences at the national and international levels were reviewed and then important restrictions and factors were selected using Delphi questionnaire, Expert Choice software, and comments of experts. Finally, given the high efficiency of AHP, TOPSIS, and SAW models, it was recommended that concomitant use of these models may lead to a more appropriate and better ranking of strategies for control and reduction of environmental pollution in developmental plans and projects.

Keywords: *Environmental Pollution; Analytic Hierarchy Process (AHP), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS); Simple Additive Weighting (SAW)*

INTRODUCTION
Stating the Problem and Research Scope
Continuation of the current trend of socioeconomic development of human society or, in other words, modern life of human seems to be very difficult without electricity. However, generation, transmission, and consumption of electricity are followed by several environmental consequences.
So, scientific and practical steps should be taken to identify and find solutions to mitigate its adverse effects, otherwise socioeconomic development will lead to lower quality of the environment and thereby endangers human health. Power plants and their operation processes produce a variety of thermal pollution, chemical water pollution resulting from the release of fossil effluent, and air pollution resulting from the use of fuels. Hence, it is necessary to apply methods and techniques that are less biased and justification-oriented.
On the other hand, in developing countries such as Iran, environmental losses are generally overshadowed by high interests and benefits of production and development activities. It is obvious that environmental losses must be first recognized and understood and then the required solutions for dealing with them and reducing their adverse effects should be determined and implemented.
Although in many cases the managers of such projects apparently support the strategies for reduction of negative environmental impacts, in practice negative environmental effects are justified with non-academic and non-professional reasons and judgments.

The present study is seeking to answer the question that how bias in human judgments about such activities can be decreased regarding the current situation in Iran. In some cases such as power plants, where more options or more complex features and factors must be evaluated, more contradictions can be seen between the statements and measures of management in these centers and the real negative environmental effects. It seems that such problems can be resolved by using Multi-criteria Decision-Making (MCDM) models. By simultaneous comparison and evaluation of three methods of decision-making (AHP, TOPSIS, SAW), the present paper aims to identify the causes of pollution, rank different types of pollution according to their outcomes regarding the effective environmental factors, and select appropriate strategies to inhibit or reduce pollution. Based on different expectations and needs of decision-makers, each of these methods, as a supporting tool for decision-making, could be accountable for different aspects of a problem. Therefore, the application of an integrated model can provide more comprehensive solutions to such complex problems.

The Importance of Research

Nowadays, the use of environmental management techniques in planning and policy-making has been accepted by most countries. One of the major operational factors in the field of environmental management in developed and developing countries is environmental assessment as an important management tool in environmental studies, reduction of the adverse effects of industrial and civil projects, and compliance with sustainable development goals. This important issue has found a legal status in Iran since 1994 (Monavari, 2002).

Environmental impact assessment can be defined as a method for detection, prediction, and interpretation of impacts of a proposed project on the environment, public health, and ecosystems that human existence and life depends on. The process of environmental impact assessment is the review of the science which leads to making decisions about implementation or non-implementation of a given proposed project (Monavari, 2002).

Power plants often produce effects and implications that are incompatible with the environment, unless environmental considerations are taken into account comprehensively and discriminately in initial designing and planning of such projects. In the usual methods of assessment in Iran, there is no specific methodology for assessment of impacts based on various environmental standards (Khodabakhshi and Jafari, 2010). Additionally, in common methods, such as check list and matrix, parameters are chosen necessarily in a way that they can be measured (Wadley, 1990).

In recent decades, researchers have focused on MCDM models for complex decisions. Instead of using one criterion for measuring optimality, several criteria may be used in such situations (Asgharpour, 2008). MCDM models have been dramatically developed and widely used because they are able to simultaneously consider the circumstances and the qualitative and quantitative variables (Zareiy and Bagheri, 2007). In such cases, a number of options are analyzed and prioritized (Momeni, 2006). Also, the views and comments of many experts on the basis of multiple criteria is needed. It has been proved by experience that much dispute on sensitive environmental projects cause the views of all beneficiaries to be taken into account.

Research Literature

Previous Studies at International Level

- Prasanta (2002) assessed the crude oil pipeline project in India using AHP and MADM techniques. In the proposed model for selection of preferred option, technical analysis, socioeconomic impact assessment, and environmental impact assessment were conducted in an integrated framework. Finally, a financial analysis was done to justify the site selection (Prasanta, 2002).

- Piers *et al.,* (2011) in a paper entitled “The use of AHP and fuzzy TOPSIS for evaluation of sustainable development of solid waste management system; a case study: Setubal Peninsula in Portugal”, studied how to integrate the above models to assist decision-makers of waste management systems in Portugal, aiming at selecting the best practices of waste management. While AHP was used to determine the weight of critical factors, screening and ranking were done by TOPSIS under uncertainty (Piers *et al.*, 2011).

- Athanasios *et al.,* (2007) used AHP to survey 10 power plants in terms of the rate and volume of non-radioactive emissions output. The studied power plants included coal, oil, natural gas turbine, NGCC, nuclear, hydro, wind, geothermal, photovoltaic, and biomass power plants. Evaluation of these 10 power plants based on lifecycle of emissions shows that nuclear, hydro, geothermal, and wind power plants are the best choice in terms of the criteria and sub-criteria. All these power plants have very low and negligible volume of emissions and have minimal effect on human health in their surrounding environment (Athanasios *et al.*, 2007).

Previous Studies at National Level

- Ebrahimi *et al.,* (2011) conducted a study entitled "Environmental assessment and measurement of some important indicators of oil pollution on the land area of Sarkhoon Gas in Bandar Abbas" and investigated the nature and behavior of pollutants and how they are emitted in underground environment. Zoning and preparation of land maps and data on pollution emission were done by Surfer and Arc GIS software and simulation was performed by MARLAB software (Ebrahimi *et al.,* 2011).
- Malmasi *et al.,* (2010) in a paper entitled "Analysis of the environmental impact of Mahshahr Petrochemical Industry using AHP", studied the activities of petrochemical industry and emissions of pollutants and their adverse environmental impacts on the existing habitats in Mahshar Special Economic Zone. The afflicted ecosystems were prioritized using AHP and Expert Choice software. The results showed that contaminants of petrochemical industry and particularly those that enter water such as heavy metals, oil, and grease (Malmasi *et al.,* 2010).
- Jozi and Saffarian (2011) identified and prioritized the risks and impacts of Abadan Gas Power Plant using TOPSIS model. The results suggested that the most important environmental risks of Abadan Gas Power Plant include commissioning with gas, fuel tanks, and gas fuel delivery in operation unit and work on liquid fuel clutch and replacement of gas filters in mechanic unit. Application of electrical current protection devices, periodic inspections, and preventive maintenance were proposed as strategies to control and reduce the identified risks (Jozi and Saffarian, 2011).
- Jozi and Shafeeiy (2009) analyzed the environmental risks of Helle Protected Area in Bushehr using Analytical Hierarchy Process (AHP). They identified 26 risk factors divided into two groups of natural disasters and environmental risks.
- Makvandi (2010) compared AHP and TOPSIS methods in assessment of environmental effects of oil refineries in Khuzestan Heavy Oil Refinery. The results showed that, unlike other assessment methods, a combination of AHP method and opinions of experts can involve the views of beneficiaries in ranking and also prevents personal thoughts to affect assessment. By using TOPSIS in environmental impact assessment, infinite options (impacts of a particular project) can be ranked based on infinite indices. High accuracy and usability of spreadsheet software are other advantages of this method (Makvandi, 2010).

A Summary of Research Literature Review

Many studies have been carried out inside and outside Iran on assessment of environmental impacts and consequences of different projects and especially those related to energy, while few studies have been conducted on models used in such studies. Further analysis showed that AHP, TOPSIS, and SAW models have never been applied in a combination for the assessment and management of environmental impacts. Due to limited experience in the use of these models in Iran, the use of them can be useful in development and analysis of management strategies in power plants.

The Study Area

Sanandaj Combined Cycle Power Plant, located in the 7th Kilometer of Tehran-Saghez Road and adjacent to the village of Ghelian, is one of Iran's combined cycle power plants with a generating capacity of 956 MW.

Established in an area of 72 acres, this power plant includes four 159-MW gas units and two 160-MW steam units. Gas and steam turbines of this power plant are of models Ansaldo 94.2V and Siemens E30-16-1x6.3, respectively, and its boilers are made by Dusan Factory. Natural gas is the primary fuel of this power plant and in cold seasons, when it is not possible to use natural gas, gasoline is used as an alternative. The maximum consumption of natural gas and gasoline by the units of Sanandaj Combined

Cycle Power Plant is, respectively, equal to 200000 m3 and 200000 liters per hour. There are two tanks with the capacities of 20000000 and 35000000 liters for saving the liquid fuel.

MATERIALS AND METHODS

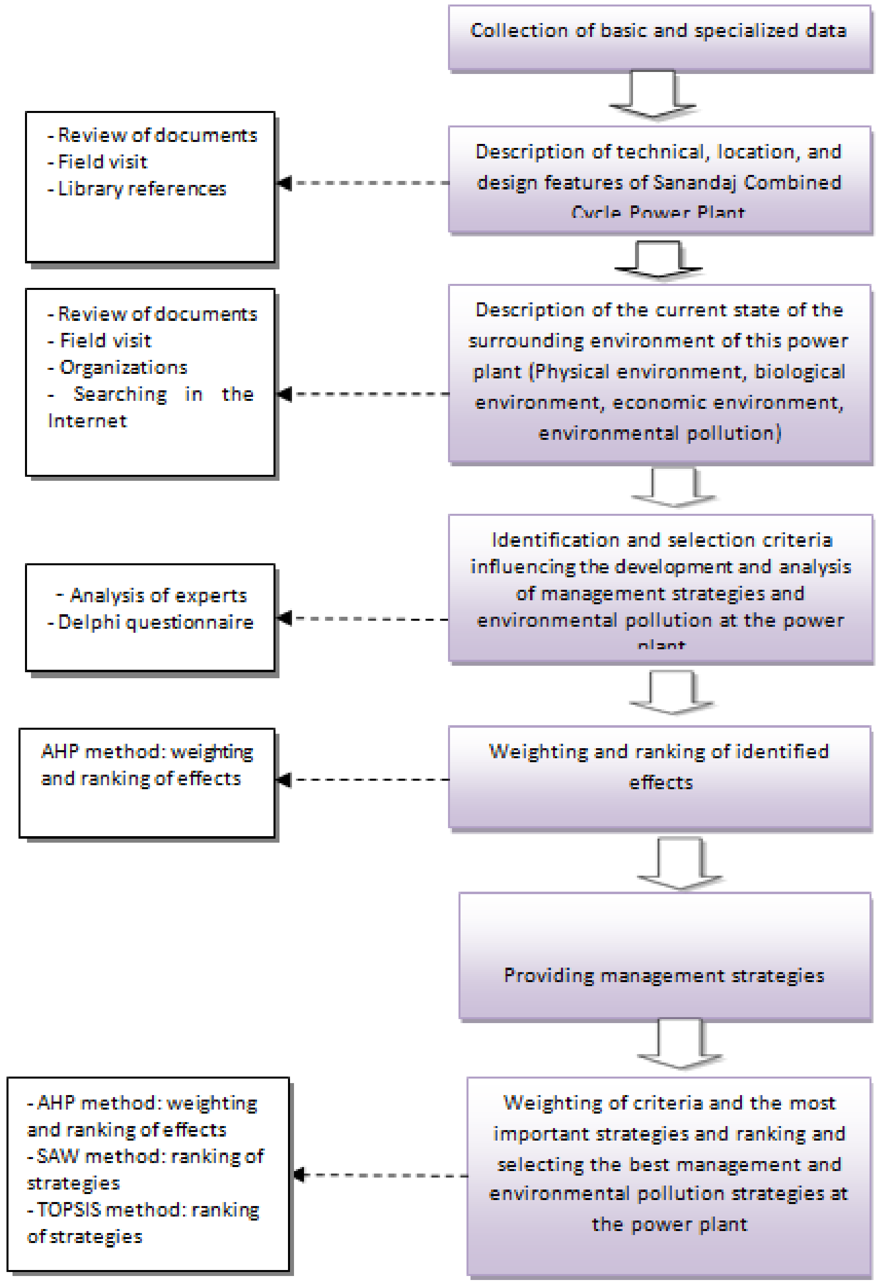

Figure 1: Process of the present study

For environmental assessment of Sanandaj Combined Cycle Power Plant, the studied area was frequently visited and inspected and the current situation in the region was evaluated, so that the impact of activities could be investigated based on geographic location and environmental issues. A questionnaire was prepared by consulting with officials and experts (university professors, Agriculture Organization, Environment Organization, Regional Water Company, etc.) and by using hierarchy method. The questionnaire was distributed in targeted organization and the required data were collected. Then,

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assessment was conducted based on the gathered information. With regard to what mentioned above, the process of the present study was as follows (Figure 1):

- Review of previous information and studies at national and international levels on the capabilities of AHP, TOPSIS, and SAW in development and analysis of management strategies in combined cycle power plants.
- Description of technical, location, and design features of Sanandaj Combined Cycle Power Plant.
- Description of the current state of the surrounding environment of this power plant.
- Application of Delphi questionnaire.
- Weighting and ranking the identified effects.
- Providing management strategies and selecting the best ones.
- Reporting

Data Collection

Collection of basic data in this study was done through reviewing library references, domestic and international references, scientific and academic centers, and state organizations such as Environmental Protection Organization of Kurdistan Province, Natural Resources Organization of Kurdistan Province, Governor's Office of Kurdistan, and other agencies. Then, a general understanding of the status of the studied area was obtained through direct observation of environmental parameters such as prominent mammals and birds, dominant vegetation, and climate. In the next step, deep and exploratory interview technique was used for more accurate design of aspects and central points of the research. The main tool for data collection in this study was a questionnaire in which different concepts were asked.

Table 1: Environmental criteria and sub-criteria affecting the development and analysis of management strategies for reducing pollution in Sanandaj Combined Cycle Power Plant

	Option	Weight	Sub-criterion	Weight	Criterion	Objective
0/406	Precipitation	0/320	Climatic condition	0/113	Physical	Ranking of environmental pollution factors in Sanandaj Combined Cycle Power Plant
0/370	Temperature					
0/078	Dominant wind direction					
0/147	Number of days of frost					
0/223	Kinds of precipitation	0/122	Water resources			
0/487	Surface waters					
0/162	Groundwater					
0/127	Flooding and distance from watercourses					
0/745	Slope of the land	0/558	Structure and topography of the land			
0/099	Altitude					
0/156	Geographical direction					
0/500	Destruction of vegetation	0/750	Vegetation and habitats	0/289	Biological	
0/500	Reduced diversity and density of vegetation					
0/082	Wildlife migration	0/250	Animal wildlife			
0/682	Destruction of animal habitats					
0/236	Loss of biodiversity					
0/634	Forest	0/089	Land usage change	0/069	Economic,	

0/206	Pastureland				social, and cultural	
0/055	Gardens and arable lands					
105	Green space					
0/635	0-5 Km					
0/287	5-10 Km	0/027	Distance to roads and other means of communication			
0/078	More than 10 Km					
0/625	0-250 meters					
0/238	250-500 meters	0/372	Distance to public buildings and industrial plants			
0/136	More than 500 meters					
0/105	Increase in educational services					
0/637	Increase in transportation facilities	0/151	Increasing the quality of life			
0/258	Increase in social services					
0/550	0-5 Km					
/210	5-10 Km	0/062	Distance to farmlands			
0/240	More than 10 Km					
0/062	Rising land and property prices					
0/289	Development of related industries					
0/536	Increased employment of local labor	0/259	Economic activities			
0/113	Migration of native people					
0/101	Low					
0/226	Moderate	0/040	Availability of qualified personnel and equipment requirements			
0/674	High					
0/072	Household and household-like waste					
0/279	Industrial waste	0/122	Waste (solid waste)			
0/649	Special waste					
0/565	Sanitary waste					
0/262	Process waste			0/536	Environmental pollution	Ranking of environmental pollution factors in Sanandaj Combined Cycle Power Plant
0/118	Oil and petroleum substances	0/320	Effluent			
0/055	Affluent containing minerals					
0/287	Primary pollutants	0/558	Air pollution			
0/635	Secondary pollutants					
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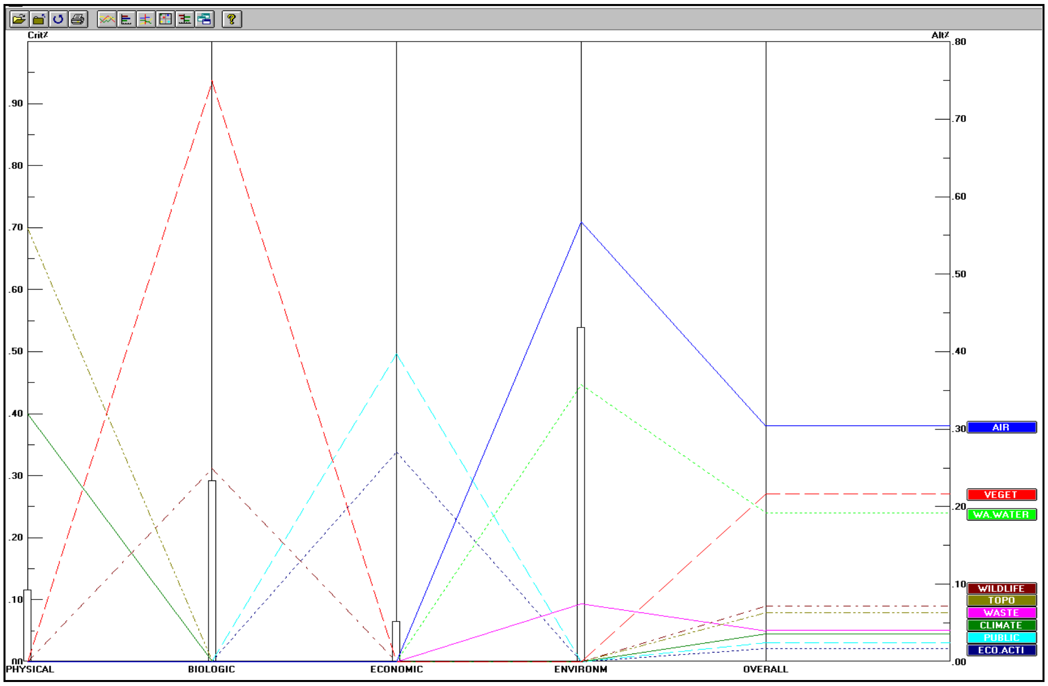

Figure 2: Analysis of functional sensitivity and dynamicity of effective sub-criteria in development and analysis of management strategies commensurate to the objective in Sanandaj Combined Cycle Power Plant

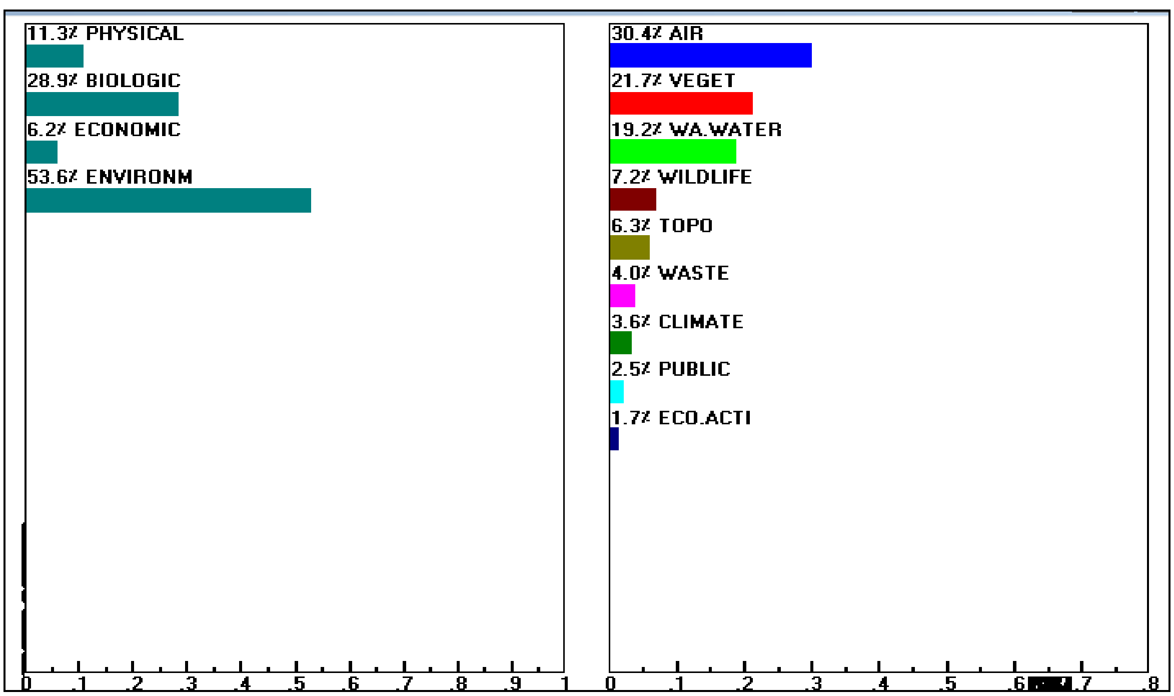

Figure 3: Analysis of dynamic sensitivity of effective sub-criteria in development and analysis of management and pollution strategies commensurate to the objective in Sanandaj Combined Cycle Power Plant

The following figure illustrates the prioritization of options commensurate to the objective. Inconsistency rate is equal to 0.05 that indicates a low level of error, as it is less than 0.1.

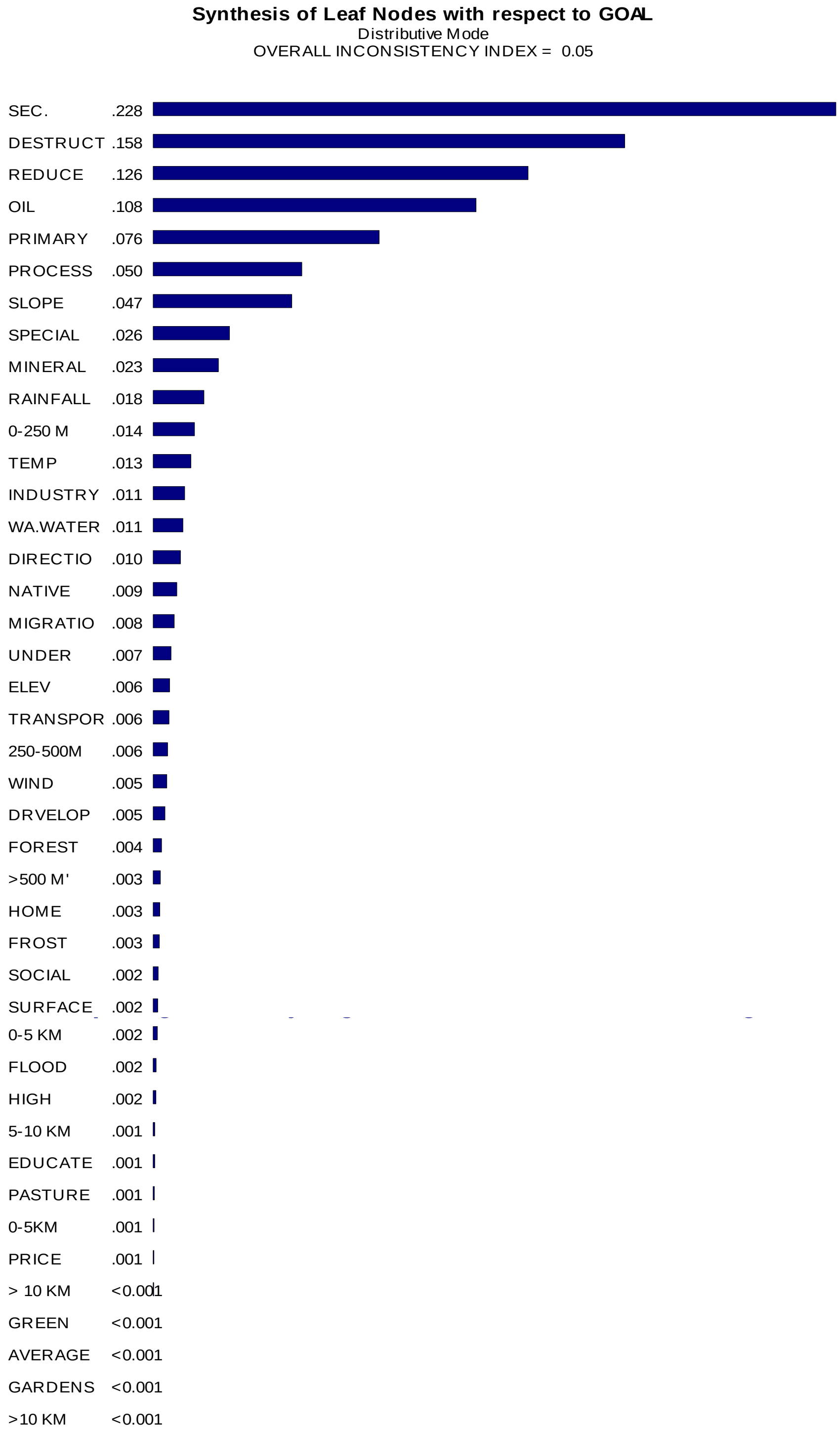

Figure 3: Prioritization of options effective in development and analysis of management and pollution strategies commensurate to the objective in Sanandaj Combined Cycle Power Plant

Since three models of MCDM including AHP, TOPSIS, and SAW were used in the present study, firstly the ranking resulted from each of these methods will be presented then they will be compared with each other. The findings of this study confirm the ability of MCDM models in combining the qualitative and quantitative criteria with different scales in prioritization.

The Results of the Prioritization of Strategies using AHP

The results of the ranking of strategies for reduction and control of air pollution suggest that strategies 1, 2, 4, 3, 5, 8, 6, 9, 7, and 10 have the highest priority, respectively. Ranking of strategies of reduction and control of water and soil pollution also shows that strategies 3, 5, 7, 1, 2, 9, 8, 4, 6, and 10, respectively, are the highest priorities. Strategies 2 and 1 are the best priorities among the strategies for reduction and control of wastewater pollution. In terms of strategies for reduction and control of normal residual contamination, strategies 1 and 2, respectively, are the highest priorities. Additionally, strategies 5, 8, 2, 7, 1, 4, 6, and 3, respectively, are the most appropriate strategies for reduction and control of industrial waste pollution.

The Results of the Prioritization of Strategies using TOPSIS

Ranking of strategies using TOPSIS allows the investigators to get use of other criteria in ranking of effects, in addition to the index of the importance of effect (intensity of effect × scope of effect). The results of the ranking of strategies for reduction and control of air pollution indicate that strategies 7, 2, 3, 1, 4, 10, 9, 8, 6, and 5, respectively, have the highest priority. Ranking of strategies of reduction and control of water and soil pollution also reveal that the best priorities include 1, 5, 4, 8, 6, 3, 9, 2, 7, and 10, respectively. In terms of the strategies for reduction and control of wastewater pollution, strategies 2 and 1 are the highest priorities. The results of the ranking of strategies normal residual pollution also suggest that strategies 2 and 1 are the best ones. In addition, strategies 2, 4, 3, 1, 8, 7, 5, and 6, respectively, have the highest priorities for reduction and control of industrial waste contamination.

The Results of the Prioritization of Strategies using SAW

Like TOPSIS, SAW method also makes it possible for investigators to get involved other criteria in ranking of effects.

Table 2: Prioritization and weighting of strategies for management of pollution using Expert Choice software in Sanandaj Combined Cycle Power Plant

The results of prioritization of strategies using SAW	The results of prioritization of strategies using TOPSIS	The results of prioritization of strategies using Expert Choice software	Classification of strategies	Number
S7> S3> S1> S4> S2> S10> S9> S8> S5 > S6	S7 > S2 > S3 > S1 > S4 > S10 > S9 > S8 > S6 > S5	S1> (0/151)S2> (0/112)S4> 0/108)S3=S5> (0/102)S8> (0/101)S9> (0/072)S6> (0/050)S7(0/196)	Air pollution management strategies	1
S1> S5> S4> S8> S6> S3> S9> S7> S10> S2	S1> S5> S4> S8> S6> S3> S9 > S2> S7> S10	S3>(0/195)S5> (0/153)S7> 0/102)S1> (0/096)S2> (0/060)S9> (0/057)S8> (0/039)S4>(0/031)S6)267(0/	Water pollution Air pollution management strategies	2
S2> S1	S2> S1	S2>(0/250)S1)750(0/	Wastewater pollution management strategies	3
S2> S1	S2> S1	S1>(0/200)S2) 800(0/	Normal residual pollution management strategies	4
S2> S4> S3> S7> S1> S8> S5> S6	S2> S4> S3> S1> S8> S7> S5> S6	S5>(0/196)S8>(0/160)S2>(0/112)S7> (0/087)S1>(0/068)S4>(0/053)S6>(0/040)S3)282(0/	Industrial waste pollution management strategies	5

The results obtained from analysis and prioritization of the effects of the studied power plant using SAW show that strategies 7, 3, 1, 4, 2, 10, 9, 8, 5, and 6, respectively, have the highest priority in reduction and control of air pollution. When it comes to strategies for reduction and control of water and soil pollution, the best priorities include 1, 5, 4, 8, 6, 3, 9, 10, 7, and 2, respectively. Also, strategies 2, 4, 3, 7, 1, 8, 5, and 6, respectively, have the highest priority for reduction and control of industrial waste pollution. In terms of strategies for reduction and control of normal residual contamination and also wastewater pollution, strategies 2 and 1 are the best priorities.

Comparing the Results of the Prioritization of Strategies using AHP, TOPSIS and SAW

Analytical Hierarchy Process (AHP) is appropriate for integration or as an additional method with other methods of assessment. Using a decision-making matrix and the integration of all criteria affecting the ranking of effects, TOPSIS and SAW are simpler and more reliable and can be used easier. AHP is an additional method for conducting other methods in tanking. This is confirmed by the studies of Nasiri (2006), Gong *et al*., (2001), and Solnes (2003). One of the advantages of TOPSIS is the ability to prioritize infinite options based on infinite indices. Prioritization by AHP is suitable when ranking of criteria is done based on only one index (here, the importance of effect). One of the advantages of AHP, compared with TOPSIS, is the inconsistency rate. Additionally, AHP has a hierarchical tree by which the effect of higher factors can be applied to lower ones and also ranking would exist in different environments. Finally, it can be concluded that TOPSIS and then SAW alone have the capability to rank the effects based on different indices and provide better results. This does not mean that AHP cannot rank the effects but its ranking is incomplete, because this method considers only the importance of effect (intensity × scope) in ranking. If other effective indices in ranking of effects are calculated and determined by other methods and gotten involved in AHP, AHP would be an appropriate method.

RESULTS AND DISCUSSION

Results

- In terms of effective parameters, the obtained results indicate that air pollution, with a weight of 0.387, is the most important type of pollution in the studied combined cycle power plant. Then, water pollution (0.217), waste water pollution (0.190), pollution caused by special and industrial residual (0.141), and pollution from ordinary residual (0.074), respectively, have the highest share of pollution.
- It is noteworthy to say that ranking and analysis of management strategies for environmental pollution is feasible by MCDM models. AHP has a good capability for weighting different environmental standards effective in analysis of management strategies for environmental pollution. So, the first and the second hypotheses are confirmed.
- The results also showed that either of SAW or TOPSIS models alone has the potential to rank management strategies for environmental pollution and the results of both models are almost identical. On the other hand, the results of ranking of strategies by AHP are completely different from the results of TOPSIS and SAW and even far from reality. Finally, the best method is a combination of these three models in which AHP is used for weighting the effective criteria and average ranking of strategies are used in TOPSIS and SAW.
- Unlike other assessment methods, a combination of AHP and opinions of experts can involve the views of beneficiaries in ranking and prevents personal thoughts to affect assessment.
- Prioritization of strategies using TOPSIS is an easier way, as all options of assessment altogether are measured in a single matrix and there is no need to make separate decisions for each option, like other methods of assessment.
- Variability in the use of these methods revealed their high efficiency in the complex process of decision-making when criteria are many and varied, as the minimum human error was involved and the most reliable results were obtained.
- Analysis of sensitivity of decision-making, the capability of prioritizing infinite options based on infinite indices, and the slightest flaw in the ranking of options are the prominent advantages of TOPSIS model which have made it more common among other MCDM models.

- Simplicity and ease of use and achieving more objective and more realistic results in analysis and ranking of effects are some of the features of SAW model.

Recommendations

1. Given the importance of information layers in Multi-Criteria Decision Making (MCDM) methods and since these criteria and their importance may vary in each region due to special environmental conditions, it is necessary that experts to both determine these parameters for each region and localize them.
2. Appropriate standards and criteria for reduction and control of environmental pollution should be determined and developed by Tavanir Company and Environmental Protection Organization of Iran based on three main perspectives of economic, functional and sustainable development in order to minimize the problems resulting from combined cycle power plants and reduce the environmental pollution caused by their activities.
3. *Air Quality Monitoring Programs:* 1- Pollutant gases: the outlet of chimney should be inspected twice a year. 2- Clean air standards: the amount of suspended solids, CO, Sox, Nox, and Co_2 in the diesel exhaust should be monitored twice a year.
4. Designing and using an advanced wastewater treatment system for collection on recycle of wastewater.
5. Technical control, monitoring, and inspection of plant facilities in all sections to prevent any kind of contamination, especially oil and fuel spill and also volatile pollutants (VOCs), in the surrounding area.
6. Periodic monitoring of exhaust emissions and identifying the reasons and modifying them if they are higher than allowed concentration.
7. Installation of social sensors in processing units to warn in the case of leakage over the limits.
8. In the present study, only effective criteria and sub-criteria in development and analysis of management strategies were investigated. To achieve a more accurate selection, other criteria and sub-criteria can be also analyzed.
9. Other models (such as ELECTRE) can be used in assessment and prioritization of strategies for reduction and control of pollution and their results can be compared with the findings of the present study.
10. The use of SWOT matrix in development of strategies can be helpful. At first, the strategies derived from this matrix can be investigated and then, according to the objective, MCDM models can be used for evaluation and selection of strategies.
11. Proposing an annual environmental monitoring program and sampling and enumerating the valuable organisms living in surrounding environment in order to protect them.
12. Development and proposal of required training programs for various sectors at professional, semi-professional, and public levels.

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