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Environmental and Technical Modeling of Industrial Solid Waste Management Using Analytical Network Process; A Case Study: Gilan-IRAN

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***Abstract*—**Proper management of residues originated from industrial activities is considered as one of the serious challenges faced by industrial societies due to their potential hazards to the environment. Common disposal methods for industrial solid wastes (ISWs) encompass various combinations of solely management options, i.e. recycling, incineration, composting, and sanitary landfilling. Indeed, the procedure used to evaluate and nominate the best practical methods should be based on environmental, technical, economical, and social assessments. In this paper an environmental-technical assessment model is developed using analytical network process (ANP) to facilitate the decision making practice for ISWs generated at Gilan province, Iran. Using the results of performed surveys on industrial units located at Gilan, the various groups of solid wastes in the research area were characterized, and four different ISW management scenarios were studied. The evaluation process was conducted using the above-mentioned model in the Super Decisions software (version 2.0.8) environment. The results indicates that the best ISW management scenario for Gilan province is consist of recycling the metal industries residues, composting the putrescible portion of ISWs, combustion of paper, wood, fabric and polymeric wastes as well as energy extraction in the incineration plant, and finally landfilling the rest of the waste stream in addition with rejected materials from recycling and compost production plants and ashes from the incineration unit.

***Keywords*—**Analytical Network Process, Disposal Scenario, Gilan Province, Industrial Waste.

I. Introduction

THE ongoing trend of industrial zones enlargement in addition with progressive use of resources and materials in these areas has led to the generation of large quantities of industrial wastes, which in turn gradually becomes a managing challenge in Iran. Generally, ISW is defined as discarded materials originated from industrial and mineral activities as well as refinery operations in gas, oil, and petrochemical facilities, power plants and etc. [1]. Due to the high potential of environmental risks associated with improper ISW disposal practices, managing of these types of wastes is a matter of significance, as reducing the probable consequences would be feasible by applying highly sophisticated methods.

The common disposal methods of ISWs include various combinations of solely management options, i.e. recycling, incineration, composting, and sanitary landfilling [2]. Depending on physical and chemical characteristics of generated wastes, any of these management scenarios would have different efficiencies. Therefore, selecting the optimum method for ultimate disposing, has been always one of the most challenging issues of the waste management field. It should be noted that a wrong choice can cause adverse environmental effects, in addition to economical lost due to the waste of money [1]-[5].

Since early 1990s the issue of waste management has been considered as a substantially complicated matter, and it was declared that different goals which were partially in contrast with each other had also been involved [6]. In other words, choosing the appropriate option of waste disposal has been a strategic issue [7] and as a result, assigning a solution for municipal solid waste management applies encountering with complicated problems in decision making.

During last decades the concern of researchers was diverted to Multiple Criteria Decision Making (MCDM) models in order to handle complicated decisions. In these types of decision making, several evaluating criteria may be used instead of one. Decision making models are divided in two general categories: Multiple Objective Decision Making (MODM) and Multiple Attribute Decision Making (MADM); MODM models are applied for designing, whereas MADM models are used for choosing optimum option [8]. According to the fact that selecting the optimum method of municipal waste management is the matter of decision making by several criteria, using MCDM models is required [9]. There are many methods extended based on MADM, including Weighted Sum, AHP, ANP, SMART, TOPSIS, ELECTRE, PROMETHEE, and Goal Programming. In this paper, the ANP method (generalized form of AHP method) has been used to choose the best option.

In the Analytical Hierarchy Process (AHP), which has been issued first in 1980 by T.L. Saaty to solve complicated economic, social and other problems, considering different quantitative and qualitative criteria the best decision would be made applying sensitivity on criteria [10]. The first step in solving a multiple criteria problem is to depict the hierarchical tree. Hierarchy is a graphical presentation of the existing

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complicated problem, in a top of which is the main goal of the problem and the other levels represent criteria and alternatives. In AHP method, using a questionnaire (attitudes of experts), the options will be subject to pair wise comparisons to form a comparative square matrix for hierarchic structure, resulting in selection of the best alternative. In AHP the dependence has to be linear and up to down or vice versa [8]. If the dependence is mutual, meaning the weight of criteria depends on weight of alternatives or vice versa, the problem will not be anymore a hierarchical one and will form a nonlinear network or system with feedback. In this case, calculation of elements' weight cannot follow the hierarchical rules and formulas [11]. To resolve this problem, T.L. Saaty presented the ANP method in 1996. The advantage of using this process is that unlike AHP, the internal dependence of criteria and alternatives will be taken into account too. Saaty developed ANP theoretically on the basis of super-matrix for mutually dependent systems and their feedbacks. In this method, network is divided into smaller clusters and all the elements of each cluster such as, i_k in cluster C1 is pair wise compared by elements of another cluster such as j_k in cluster C2 (Fig. 1).

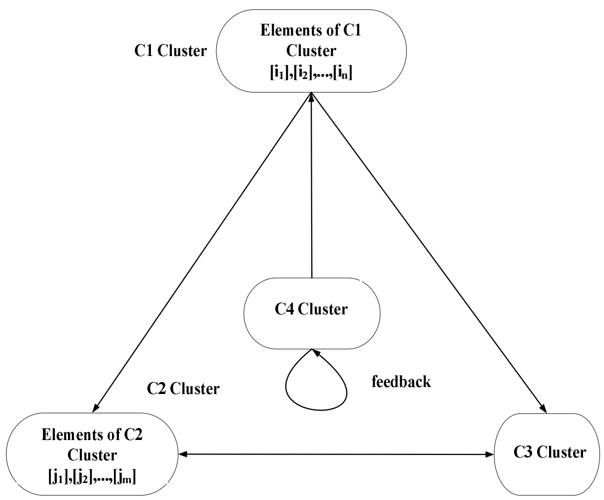

Fig. 1 Structure of Network Analysis for a Multi-Criteria Decision Making Issue

The preference among the elements of clusters is identified and forms the square comparative matrix. Finally, the ultimate comparative matrix of all elements (unweighted super matrix) will be multiplied to the weight of clusters and form the weighted super matrix. By raising this matrix to high power, the final weight vector of each option will be obtained and the one that has the most weight will be chosen as the best option [10].

Thus far many surveys have been conducted on the context of solid waste management. Morrissey and Browne (2004) have suggested that a comprehensive municipal waste managing system, not only should be environmentally and economically effective and practical, but also has to be socially acceptable [12]. Karagiannidis and Moussiopoulos (1998) performed a series of attributes, including technical, economical, environmental and social aspects, in order to find the optimum solid waste management scenario [13]. Besides, similar researches have also been conducted subject to choose the best solid waste management scenario in different parts of the world [9], [14], [15], [16]. In these researches, utilizing hierarchical and network analysis, the scenarios were designed and evaluated from the technical, environmental and economical points of view.

Likewise, many researches on industrial solid waste have been conducted in Iran. Abduli has studied the industrial waste of Tehran and obtained the dependence between weight and volume of produced wastes with the number of active workers in workshops [1]. In another research, the quantitative and qualitative properties of waste in Bu-Ali industrial estate in Hamadan, Iran were studied. This survey denoted that if there is information about waste components and domestic waste generation per capita, it would be possible to proceed to establish an appropriate managing system in order to handle industrial wastes [3]. According to the other surveys which have been conducted in Iran [4], [5], it could be concluded that the main focus of these researches was on the characterization of waste stream generated at the studied area. A general managing system with the capability of being generalized to other locations in Iran has not been defined in the mentioned surveys and in most of them suggesting a unique procedure for the ultimate disposal of all ISWs was attempted. Considering the properties of industrial waste that face with many changes in quantity and quality according to the type and number of active industries in each industrial area, the latter point is one of the main problems of previous studies. The necessity of developing an integrated managing system as the result of these surveys is also proved but the state of achieving this goal have not been discussed in detail.

In this paper the ISWs originated from Gilan industries (Fig. 2) are investigated and the best technical and environmental managing system is suggested applying ANP method. Because of the high ground water level in most of the locations of this province, the importance of choosing a scenario with the lowest adverse effects on surface water and groundwater is completely clear.

The results of a research conducted on categorizing ISWs in the Gilan province (in 2005), the whole industrial units (1,976 units) were divided into eight different groups: food; medical and sanitation; textile and leather; nonmetal mineral; metal industry and domestic appliances; electricity and electronics; car and automotive; and casting and roller equipments. In this survey 142 industrial units were chosen not randomly but specifically, and general information about the geographical location of industrial centers, the rate of generated waste in the production line, volume of generated waste, seasonal changes in quality and quantity of waste, density, porosity, humidity, toxicity, the capability of form a mixture with water, ignition properties, corrosion, corruptibility, and also recycling capacities, was obtained from each unit applying the questionnaires [4].

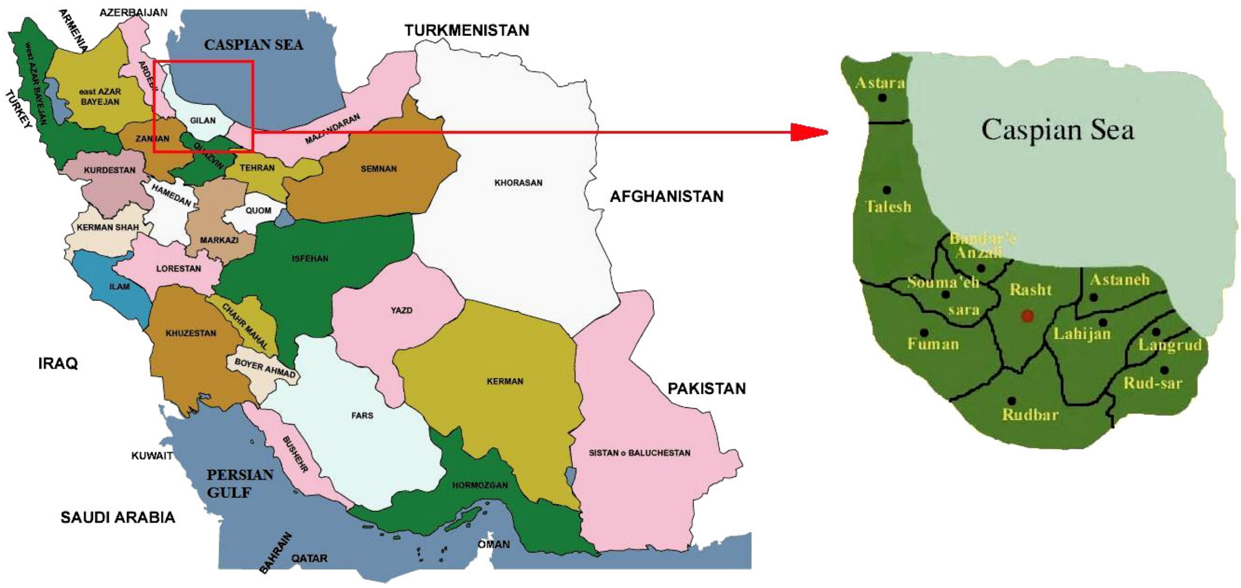

Fig. 2 Geographical location of the studied area

Obtained results from above-mentioned research indicate that all ISWs generated at Gilan province are about 150,000 tonne/yr and different industrial groups generate a wide variety of wastes (86 types). Among different industrial groups, textile and clothing units with four types of wastes have the least variety and food, medical and sanitation industries have the most (35 types of wastes) variety in generated solid wastes. The 86 types of generated solid waste in the area can be divided into seven different groups. The comparative amplitude of the solid waste stream of different industries is presented at Table 1.

It should be mentioned that in this paper, by using quantitative and qualitative information about ISWs of Gilan [4], four scenarios were designed to manage these wastes. Afterward, by applying ANP method, the best scenario have chosen and by analyzing different divisions, some procedures would be introduced to optimize existing managing system.

TABLE 1
DIFFERENT GROUPS OF INDUSTRIAL SOLID WASTES GENERATED AT GILAN PROVINCE AND THEIR RATIOS [4]

Waste Group	Generation Rate (t/yr)	Types of Generated Wastes	Percent of Total (%)
Putrescible Materials	61,448	Sunflower seed, olive, corn, soya, tea, citrus fruits, potato chips, macaroni, fish oil, flour, bean, meat, chicken, sugar, tobacco, vegetable, cigarette	41.2
Polymeric Wastes	14,099	Polyethylene dishes, nylon, plastic bags, polypropylene dishes, ABC, PVC, polystyrene, sponge, fiberglass, rubber, polyethylene terephthalate	9.5
Metals	20,618	Metal barrel, aluminum foil, metal can, iron film, brazen capsule valve, aluminum film, metal pipe and profile, bronze rebar, crimson wire, brazen wastage, medical needle, iron rebar	13.8
Chemical Wastes	27,036	Chimney color, lime, glycerin sludge, acidic and medicinal sludge, press filter dust and wastage, ink, asbestos, phenol formaldehyde, phosphate, oil wastage, urea, industrial oil, electroplating sludge	18.1
Inert Materials	11,192	Quartz, fire brick, sand, tile, cement powder, concrete, broken block	7.5
Wood and Paper Discards	14,318	Wax paper, wooden box, paper cut wastage, saw dust	9.6
Fabric and Textile Discards	346	fabric and fiber	0.2
Total	**149,057**	**------------**	**100.0**

II. METHODOLOGY

A. Scenario determination method

Table 1 indicates different groups of ISWs in Gilan province. Considering the wide variety of waste in the studied area, various kinds of methods can be used to manage them. In this research, four scenarios have been investigated. The main approach in designing these scenarios was to consider climatic conditions of the area (the high groundwater level and Caspian temper climate) and to attempt recycling most of the valuable entries among waste stream. The boundary of scenarios begins at the point of discarding the wastes and delivering them to municipality agencies, and continues to be landfilled ultimately or be rendered to recycling factories.

B. Evaluation Method

As stated before, in this paper evaluation of industrial waste management scenarios in the Gilan province was conducted from environmental and technical point of views applying ANP method. Figure 3 represents recommended network. Evaluations were accomplished by a survey on experts of waste management and summing up their attitudes and also the experiences of authors of this paper.

III. CONCLUSION AND DISCUSSION

A. Determination of scenarios

As mentioned above, considering climatic properties and integrated ISW management strategies applied at the studied zone, four scenarios as discussed bellow were examined in this paper. Scenario "A" is the simplest method of waste management. In this method, all the generated waste is transferred to the sanitary landfill site. However, because of high potential of corruptibility of some entries of waste stream, producing compost is also considered (scenario "B"). Considering the possibility of recycling some sorts of valuable waste stream, in scenario "C", recycling is applied besides the landfilling and composting. In addition, because some of the wastes with high thermal potential are transferable to incinerator plant, the incineration process can be used in order to energy extraction strategies (scenario "D"). In other words, scenario D is a comprehensive one which includes landfilling, composting, recycling and incineration. Following, describes the procedure of 4 considered scenarios (Figs 4-7).

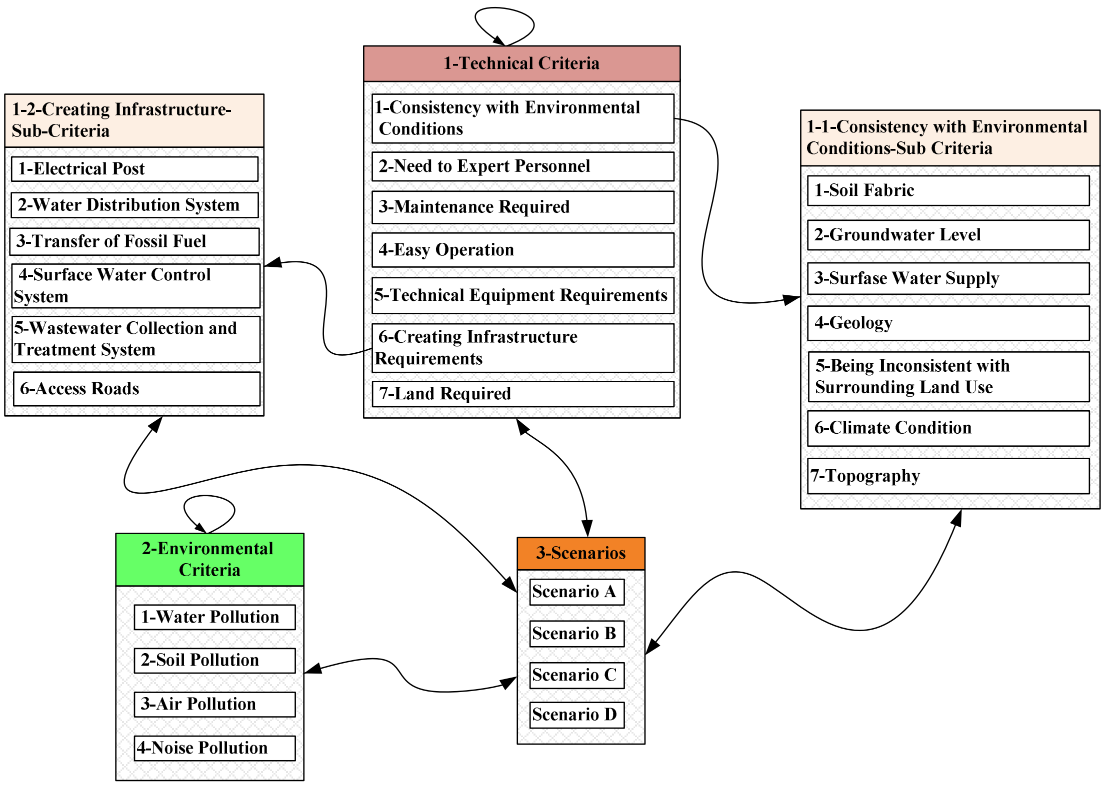

Fig. 3 Components of proposed ANP network model

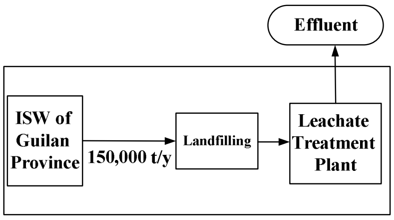

Fig. 4 Scenario A

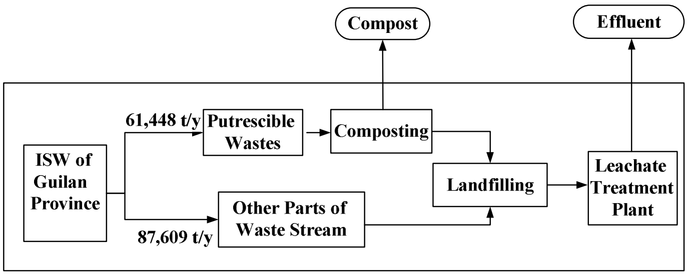

Fig. 5 Scenario B

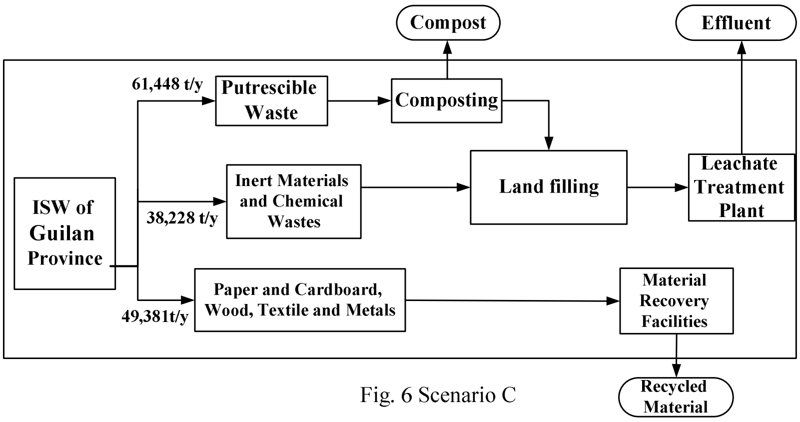

Fig. 6 Scenario C

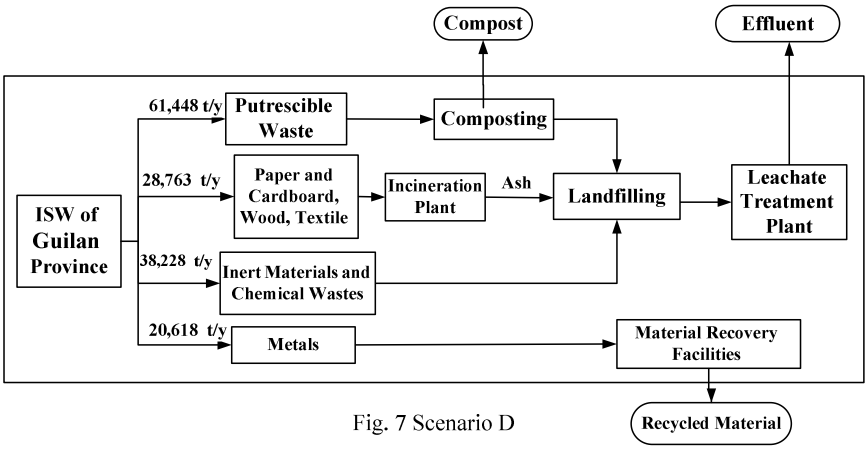

Fig. 7 Scenario D

B. Evaluating the scenarios

In this stage, the existing elements in technical and environmental clusters and sub-criteria of "consistency with environmental conditions" and "technical equipment requirement" were compared one by one with each other and the scenarios, applying the attitude of experts, and the preference was determined. The comparison was modeled in Super Decision software (version 2.0.8), the way the software works with criteria and sub-criteria clusters are shown in Fig. 8 along with their external and internal links. The extents such as high groundwater level in the area, soil fabric, and being adjacent to residential/aesthetic/archeological/tourist areas, environmental criteria weights have been considered more than technical ones. In Table II weights of these criteria and sub-criteria are indicated comparing to the scenarios.

As Table II indicates, due to high groundwater level, "water pollution" and "soil pollution" elements are two environmental criteria which weigh more than the others. "Air pollution" and "noise pollution" are the next ranks in that Table, respectively. Also "Need to Expert Personal", "Surface Water Control System", "Access Roads" and "Land Required" are playing major roles in selecting the best disposal scenario.

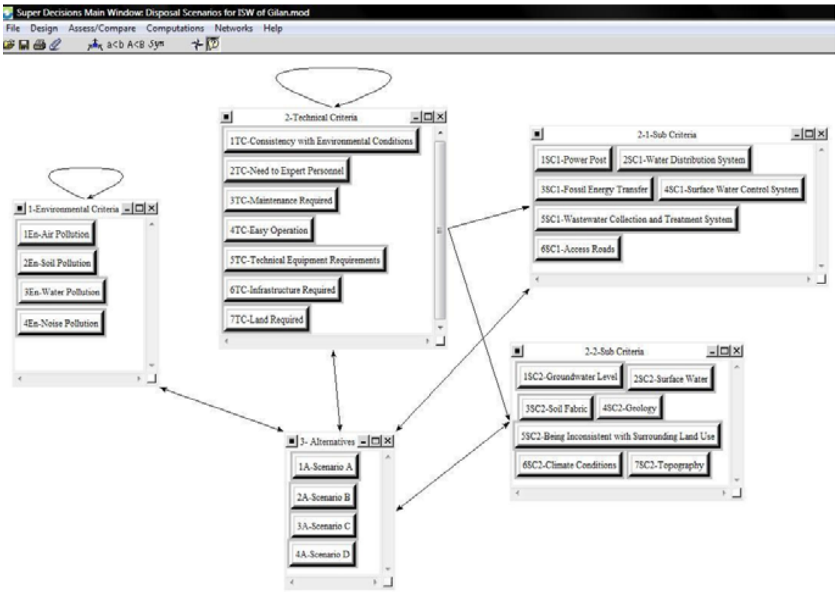

Fig.8 Super Decisions model

TABLE II
PRIORITIES FOR CRITERIA AND SUB-CRITERIA

Name	Normalized By Cluster	Limiting
1-Consistency with Environmental Conditions	0.1204	0.0087
1-1-Groundwater Level	0.1658	0.0089
1-2-Surface Water	0.2114	0.0113
1-3-Soil Strata	0.1096	0.0059
1-4-Geology	0.0932	0.0050
1-5-Conflict with Surrounding Land Use	0.1658	0.0089
1-6-Climate Conditions	0.0932	0.0050
1-7-Topography	0.1611	0.0086
2-Need to Expert Personal	0.1970	0.0142
3-Maintenance Required	0.1433	0.0103
4-Easy Operation	0.1070	0.0077
5- Technical Equipment Requirement	0.1383	0.0100
6-Infrastructure Required	0.1225	0.0088
6-1-Power Post	0.1268	0.0068
6-2-Water Distribution System	0.1221	0.0066
6-3-Fossil Energy Transfer	0.1565	0.0084
6-4-Surface Water Control System	0.2386	0.0128
6-5-Wastewater Collection and Treatment System	0.1190	0.0064
6-6-Access Roads	0.2370	0.0127
7-Land Required	0.1716	0.0124
8-Air Pollution	0.2012	0.0857
9-Soil Pollution	0.2807	0.1196
10-Water Pollution	0.3596	0.1532
11-Noise Pollution	0.1584	0.0674

Regarding the nature of scenario A, weight of this scenario is the most in compare with technical criteria. The reason is the simplicity of its performance, whereas scenario D, according to its environmental risks, and because of the less pollutant emissions is considered as the best one. Eventually, regarding the effect of both environmental and technical criteria and accomplishment of entire comparisons, Table 3 contains final weights of scenarios.

TABLE III
FINAL WEIGHTS OF SCENARIOS

Name	Ideals	Normals
Scenario A	0.6365	0.2073
Scenario B	0.6387	0.208
Scenario C	0.7952	0.2590
Scenario D	1.0000	0.3257

As can be seen in Table 3, Scenario D, the combination of composting, recycling, incineration and sanitary landfilling is the best one and scenario A, in which the whole waste stream goes to landfill site, is the worst from environmental and technical points of view. Due to great amounts of pollutants emission in air, water and soil body and leachate produced in this scenario, it is selected as the last operating option.

Also in Scenario B which is a combination of composting and landfilling as shown in Fig. 5, despite the fact that the entry of landfill is reduced to 70% of waste stream by weight (20% of waste stream to the composting plant and the rest of the waste), composting process has its own disadvantages. Eventually, the final weights of scenarios A and B are so close to each other. It should be mentioned that adding economical evaluation criteria to the offered system in figure 3, can affect the priority of scenarios significantly (for example, the incomes obtained by selling the final compost). Yet, as it was mentioned before, economical criteria were not considered in this research.

IV. Conclusion

In present paper, considering the studies performed in 2005 on determining categories of ISWs in the province of Gilan [4], four scenarios were designed. These scenarios included one or a combination of industrial solid waste managing options (recycling, sanitary landfilling, composting, and incineration) and the best environmentally and technically appropriate scenario was selected applying ANP method. Evaluation of technical part was performed based on sub-criteria consisted of consistency with environmental conditions, need to expert personnel, maintenance required, easy operation, technical equipment requirements, need to build infrastructures and land required; and in evaluation of environmental criteria, instances like noise pollution, probability of pollutant emission into water, soil and air media were considered. Afterward, all the scenarios, criteria and sub-criteria were compared pair wise. Eventually, scenario D which was a combination of landfilling, composting, recycling and incineration was chosen among four scenarios. In addition, applying economical evaluations may have a significant effect on choosing applicable Scenario in the studied zone.

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