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APPLICATION OF SENSITIVITY ANALYSIS FOR ASSESSMENT OF ENERGY AND ENVIRONMENTAL ALTERNATIVES IN THE MANUFACTURE BY USING ANALYTIC HIERARCHY PROCESS

Multi-criteria decision making (MCDM) was used to make comparative analysis of projects or heterogeneous measures for prioritization criteria and subcriteria simultaneously in a complex situation. The aim of this paper is to determine the alternatives and the sensitivity of main factors affecting water and energy consumption as well as environmental impact in a recycled paper manufacturing by using analytic hierarchy process (AHP). The AHP enables one to consider all the elements of decision process in a model, and to compare criteria and subcriteria of the model to find the best alternative. The AHP technique is applied through specific software package with user-friendly interfaces called Expert Choice. The results indicated that reduction of water consumption is the most important alternative for sustainable development in a recycled paper mill in Iran. Also, good housekeeping is the most sensitive criterion affecting the alternatives. The paper illustrates how the AHP method can help industrial management to overcome the energy usage and environmental impact in the manufacture.

1. INTRODUCTION

In accordance with the ever-increasing rate of Iran's population, the consumption of energy and products is increasing each year. With increasing energy consumption and CO_2 emissions, concern for environmental preservation increases. The efficient use of energy is a very important issue for the processing industries, business and ser-

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vice sectors, residential growth and agriculture. There are not only monetary benefits to proper energy use, but also a growing recognition that efficient use of energy supports a cleaner environment. Environmental management has an especially important role in the forest industries. Historically, the pulp and paper industry has been considered to be a major consumer of natural resources (raw material, water) and energy (fossil fuel, electricity) and a significant contributor of environmental pollution.

Papermaking is a vast multi-disciplinary industry that has expanded tremendously in recent years. Significant advances have been made in all areas of papermaking, including raw materials, production technology, process control and end products. In particular, modern papermaking would not be possible without advanced process controls and diagnostic methods. The pulp and papermaking industry is a very water-intensive industry and ranks third in the world, after the primary metals and chemical industries, in fresh water consumption. The pulp and paper industry is also one of the most significant sources of greenhouse gases, acidifying and atrophying compounds and troposphere ozone precursors, human toxicity compounds and solid waste [1].

Recycled paper production is the most common process for producing paper and paperboard in Iran. The production process contributes to many environmental problems, largely caused by emission of pollutants from the combustion of fuel and chemical processes during production. Cleaner production implementations are strategically important for production design to ensure that manufacturing systems can cope with environmental changes. Cleaner production aims at making more efficient use of natural resources and reducing the generation of waste and emissions.

Environmental problems caused by recycling waste paper at a paperboard mill provide the background for this study. The importance of re-orienting pollution control efforts away from end-of-pipe approaches toward integrated prevention has been recognized. Cleaner production concepts are recognized as a driving force behind the implementation of cleaner production strategies. Used in complement with other elements of sound environmental management, cleaner production (CP) is a practical method for protecting human and environmental health and for supporting sustainability. This concept refers to product development and production targeted at a decrease in process waste generation, resulting in reduced environmental impacts throughout the product life cycle. It is the continuous application of this integrated preventative environmental strategy to processes, products and services that holds the potential for increasing efficiency and reducing the risks to humans and the environment.

The cleaner production approaches that can be applied to production processes include recycling, process modification, plant operation improvement and input substitution. Cleaner production can also be obtained through product redesign, modification of the production processes and use of less hazardous chemical constituents. The necessity of adopting such a program in Iran was reviewed in detail, and it was determined that implementation of cleaner production is urgently needed due to high energy consumption, technical limitations, lack of competitiveness, the increased role of small-medium enterprises (SMEs) and critical environmental conditions in certain regions of Iran [2]. Ghazinoory and Huisingh [3] summarized the Iranian SME barriers to implementing cleaner production schemes such as lack of professional management, poor record keeping, resistance by decision makers, limited technical capabilities and access to technical information, unstable finances, and high cost combined with limited low availability of capital for CP. Ghorbannezhad et al. [4] indicated that cleaner production is a practical method for product development characterized by a decrease in waste generation, resulting in a reduced environmental impact throughout its life cycle. In order to achieve insight about the main criteria and subcriteria that define the potential for implementing cleaner production in paper mills, this research project began with an investigation of papermaking processes.

1.1. PAPER PRODUCTION

Stored recycled paperboards are transferred to the pulper and then to refining system where they are mechanically processed to form pulp. Raw materials are refined to produce the optimal fiber quality. The pulp is then screened to remove impurities and residual fibers. The accepted paper fiber is sent to the mixing tank. During mass preparation, the mixture has an adjusted consistency of approximately 3%. The pulp is diluted to about 1%, screened and centrifugally cleaned before being sent to the paper machine head box, where paper production is initiated. The head box is responsible for very important distribution of suspended fibers into the forming section. The operation of the head box influences the quality of the paper sheet, production capacity and efficiency of the paper machine. After leaving the head box, the fiber suspension is dewatered on the forming wire utilizing foils and suction boxes. The next stage in the process takes place in the press section, where the sheet dryness increases from 16–18% to 43%. The press section imparts important properties to the paper including the correct sheet density and is the most economical method of water removal at this part of the process. After the press section, the sheet is heated in the dryer section to increase the dryness to 90%, which is its natural moisture level. White water extracted in the forming section has considerable fiber content. A clarification system separates this water into two components: clean water for reuse and recovered fiber that is sent back to the production line. Figure 1 provides a flow diagram of the major pulp and paper manufacturing processes [5].

The Kaveh Paper Industries mill in Tehran produces 120 t/d paperboard from recycled waste paper and paperboard. The mill is highly water dependent, consuming 11.5 m^3 freshwater/t in the production of paperboard and also utilizes an average of 2.5 kg of steam/kg of evaporated water for its drying processes. In contrast, standard water consumption in the recycled paperboard industry is 4–7 m^3 freshwater/t for paperboard, and the average steam consumption in the dryer is 1.1–1.3 kg of steam/kg of evaporated water [6].

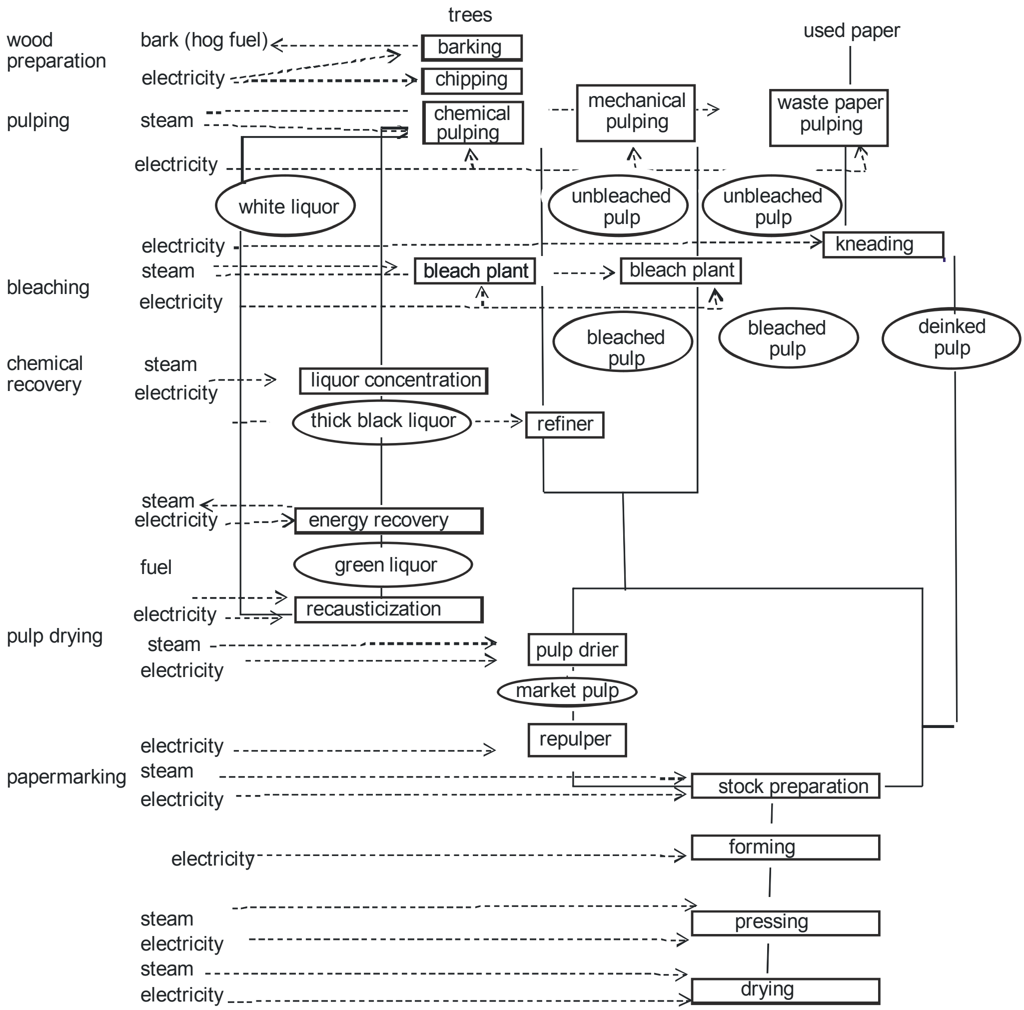

Fig. 1. Schematic of the major pulp and paper manufacturing processes

Shi et al. [7] indicated that a high initial capital cost is one of the most prominent barriers to the implementation of cleaner production in Chinese SMEs. Several methods have been suggested for successful CP introduction and implementation [8]. In order to illustrate the potential for reducing initial costs for implementation of CP techniques within the Iranian paper industry, this study utilizes the analytic hierarchy process (AHP) to prioritize and select the best CP elements and alternatives for use in Iran's Kaveh paper mill. A sensitivity analysis of the results was also performed.

2. METHODS

Decision makers require useful tools to make environmentally sound decisions that lead to effective management of hazardous wastes. An industry should integrate environmental concerns at all levels of decision making in order to prevent pollution [9]. The AHP developed by Saaty [10] determines the relative importance of a set of activities in a multi-criteria decision problem. The process makes it possible to concurrently incorporate judgments on intangible qualitative criteria with tangible quantitative criteria into an analysis of alternatives. The AHP method is based on three steps: model structure; comparative judgment of the alternatives and criteria; and synthesis of the priorities. In the literature, the main developments in AHP have been widely used to solve many complicated decision making problems [11].

In the first step, a complex decision problem is structured as a hierarchy. AHP initially breaks down a complex multi-criteria decision making problem into a hierarchy of interrelated decision elements (criteria, decision alternatives). The objectives, criteria and alternatives are then arranged in a hierarchical structure similar to a family tree. This hierarchy has at least three levels, with the overall goal of the problem at the top, multiple criteria that define the solution alternatives in the middle and decision alternatives at the bottom [12].

The second step is the comparison of the alternatives and criteria. Once the problem has been decomposed and the hierarchy is constructed, a prioritization procedure is conducted to determine the relative importance of the criteria within each level. The pair-wise judgment starts at the second level and finishes with the lowest level alternatives. In each level, the criteria are compared pair-wise according to their levels of influence and based on specified criteria in the higher level. In AHP, multiple pair-wise comparisons are based on a standardized comparison scale of nine levels (Table 1).

Table 1

Standardized comparison scale of nine levels

Definition	Importance ranking
Equally important	1
Moderately more important	3
Strongly more important	5
Very strong more important	7
Extremely more important	9
Intermediate values	2, 4, 6, 8

Let $C = \{C_j | j = 1, 2, \ldots, n\}$ be the set of criteria. The result of the pair-wise comparison on n criteria can be summarized in an $(n\times n)$ evaluation matrix A in which every element a_{ij} (i, j = 1, 2, …, n) is the quotient of weights of the criteria, as shown in Eq. (1):

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \qquad a_{ii} = 1, \qquad a_{ij} = \frac{1}{a_{ji}} \tag{1}$$

where a_{11} represents the comparison between element i and element j.

At the final step, the mathematical process commences to normalize and identify the relative weights for each matrix. The relative weights are given as the eigenvector (**W**) corresponding to the largest eigenvalue (λ_{max}), as

$$\mathbf{A} \times \mathbf{B} = \lambda_{max}\mathbf{W} \tag{2}$$

where λ_{max} – the maximum eigenvalue and **W** – eigenvector corresponding to λ_{max}.

If the pair-wise comparisons are consistent, the matrix **A** has the rank n and $\lambda_{max} = n$. In this case, weights can be obtained by normalizing any of the rows or columns of **A**.

An important advantage of AHP over other algorithmic methods is that it takes into account inconsistencies in the preferences. Inconsistencies exist because of the redundant information relating to the priorities in each decision matrix. If the inconsistency exceeds 0.10, some revisions of judgments may be required. When the inconsistency ratios are below 10%, the decision matrices that are prepared for the criteria are consistent. The quality of the output of the AHP is strictly related to this consistency of the pair-wise comparison judgments. The consistency is defined by the relationship between the entries of **A**: $a_{ij} \cdot a_{jk} = a_{ik}$. The consistency index (CI) is

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3}$$

where λ_{max} is the largest eigenvalue of the judgment matrix **A**, and n is the rank.

Table 2

Random consistency index (RI) [10]

Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The final consistency ratio (*CR*), which allows one to conclude whether the evaluations are sufficiently consistent, is calculated as the ratio of the *CI* and random index (*RI*), as indicated in the equation:

$$CR = \frac{CI}{RI} \tag{4}$$

where the random index (*RI*) is given in Table 2.

The consistency ratio (*CR*) provides a measure of the probability that matrix ratings were randomly generated. The value of 0.1 is the accepted upper limit for *CR*. If the final consistency ratio exceeds this value, the evaluation procedure has to be repeated to improve the consistency of the respondent answers. In addition to its use in measuring the consistency of decision making, the *CR* measure can also be used to evaluate the consistency of all the hierarchy [13].

After the calculation of the priorities of each criterion with respect to the goal, the alternatives are re-evaluated against each criterion for all stages of the hierarchy.

2.1. SENSITIVITY ANALYSIS

The final priorities of the alternatives are heavily dependent on the weights attached to the main criteria. Small changes in the relative weights significantly impact the final ranking. Since the relative weights are generally based on highly subjective judgments, the stability of the ranking under varying criteria weights must be tested.

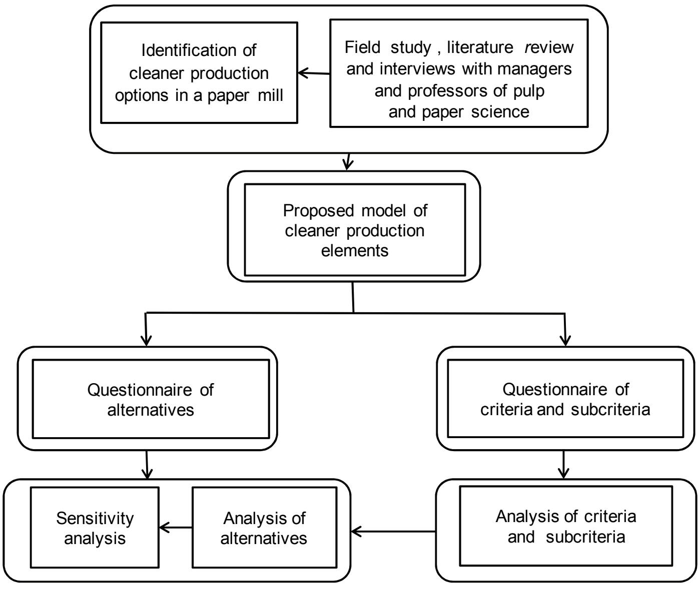

Fig. 2. A framework for the application of AHP for cleaner production implementation

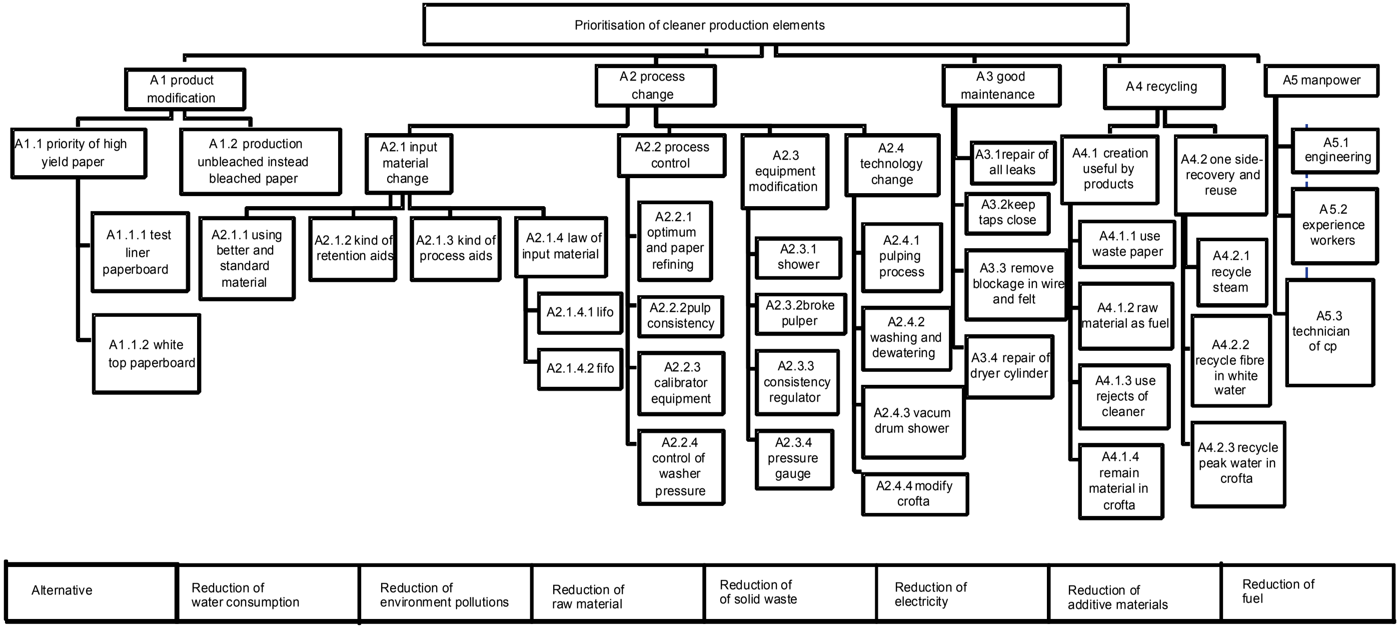

Fig. 3. A hierarchy model of CP implementation

For this purpose, a sensitivity analysis can be performed based on scenarios that reflect alternative future developments or different views on the relative importance of the criteria. The implementation of AHP in Expert Choice provides four graphical sensitivity analysis modes: dynamic, gradient, performance and two dimensional. Performance sensitivity analysis was employed in this study and depicts how well each alternative performs relative to each criterion by increasing or decreasing the importance of the criteria.

A framework for the application of AHP for cleaner production implementation is illustrated in Fig. 2. First, on the basis of the literature review, field study and individual interviews of mangers and professors, 35 subcriteria were identified and grouped into five categories. Second, a tree-hierarchy was structured to facilitate the prioritization process (Fig. 3). The tree was segmented into five levels: the top level contains the cleaner production elements; the second level contains five categories. The five levels contain a total of 35 subcriteria. Third, the questionnaires were categorized into two separate series, ten of which were for criteria prioritization and the other ten which dealt with prioritization of the alternatives. The questionnaires were distributed to four academics, one upper manager, one mill manager, two quality control engineers and three highly skilled technicians. The surveys were administrated through individual personal interviews. A questionnaire delivered to one of the technicians required correction due to a high inconsistency ratio. Fourth, after the initial solutions with assigned weights of criteria, subcriteria and alternatives were obtained, sensitivity analyses were performed to explore the response of all of the alternatives to the change in the relative synthesis value of each criterion. The performance sensitivity of each alternative was analyzed using Expert Choice 2000 software, the first software developed for AHP applications and among the best commercial software for multi-attribute decision making. Expert Choice is decision support software that reduces complex decisions to a series of pairwise comparisons and then synthesizes the results. Expert Choice software first calculates the local and then the global weights of each objective and sub-objective [14].

In this study, the proposed model was used to prioritize the elements of cleaner production with low initial cost in the recycled paper mill. These elements have economic and environmental advantages and a short period payback. AHP was applied to prioritize quantitative and qualitative elements of cleaner production and alternatives and to provide a step-by-step plan to implement cleaner production in the industry. Use of local personnel experiences for implementation of cleaner production is possible using the AHP method and will be both economic and affordable.

3. RESULTS

3.1. CRITERIA AND SUBCRITERIA

As shown in Table 3, the A2. Process change main category is the most prominent CP criterion, with a normalized global weight of 0.302 on the second hierarchy level.

Table 3

Local and global criteria and subcriteria of all cleaner production elements

Element	Weight		Element	Weight	
	Local	Global		Local	Global
A1. Product modification	0.123	0.123	A2.4. Change technology	0.258	0.058
A1.1. Product high-yield varieties of paperboard	0.654	0.080	A2.4.1. Modify pulping process	0.228	0.022
A1.1.1. Test liner paperboard	0.589	0.047	A2.4.2. Modifying washing and dewatering, e.g. by using twin-wire belt press	0.274	0.021
A1.1.2. White top line paperboard	0.411	0.033	A2.4.3. Use vacuum drum shower	0.190	0.015
A1.2. Product unbleached instead of bleached paperboard	0.346	0.043	A2.4.4. Modify Krofta process*	0.248	0.019
A2. Process change	0.302	0.302	A3. Good maintenance	0.249	0.249
A2.1. Input material change	0.324	0.98	A3.1. Repair all leaks	0.468	0.117
A2.1.1. Using better and standard raw material	0.410	0.040	A3.2. Keep taps closed when not in use	0.103	0.026
A2.1.2. Kind of retention aids	0.268	0.026	A3.3. Remove blockage in wire and felt shower	0.170	0.042
A2.1.3. Kind of process aids	0.195	0.019	A3.4. Modification and repair of dryer cylinder	0.258	0.64
A2.1.4. Law of input raw material to product line	0.127	0.012	A4. Recycling	0.158	0.158
A2.1.4.1. LIFO	0.714	0.009	A4.1. Creating useful byproduct	0.555	0.88
A2.1.4.2. FIFO	0.286	0.004	A4.1.1. Use water fiber	0.305	0.027
A2.2. Process control	0.228	0.069	A4.1.2. Use raw material as fuel in boiler	0.248	0.021
A2.2.1. Optimum and proper refining	0.384	0.026	A4.1.3. Use rejects of cleaners	0.233	0.020
A2.2.2. Refined at the highest possible pulp consistency	0.123	0.009	A4.1.4. Use remaining material in Krofta (like sludge)	0.220	0.019
A2.2.3. Install calibrator equipment	0.372	0.026	A4.2. One-site recovery and reuse	0.445	0.070
A2.2.4. Control of water pressure in the edge of cutting paper	0.120	0.008	A4.2.1. Recycle steam condensed	0.504	0.036
A2.3. Equipment modification	0.372	0.026	A4.2.2. Recycle fiber in white water	0.250	0.018
A2.3.1. Install efficient shower	0.236	0.014	A4.2.3. Recycle peak water in Krofta	0.246	0.017
A2.3.2. Provide broke pulper	0.146	0.008	A5. Manpower	0.168	0.168
A2.3.3. Install consistency regulator	0.280	0.016	A5.1. Engineering and educational technicians	0.391	0.066
A2.3.4. Use pump of adequate	0.180	0.010	A5.2. Experienced workers	0.261	0.044
A2.3.5. Install pressure gauges for water consumption control	0.157	0.009	A5.3. Professional and technician in CP	0.348	0.058

[1]Trade name for dissolved air flotation technology for wastewater treatment and fiber fines re-

covery.

Input material change A2.1, process control A2.2, equipment modification A2.3 and technology change A2.4 are the four main criteria in this category. The A3. Good housekeeping category follows, with a global weight of 0.249. The global weights of the A5. Manpower, A3. Recycling and A1. Product modification categories are less than half of the total weight. At the third hierarchy level, A2.1. Material change is regarded as the most prominent CP subcriterion under the A2. Process change category, with a local weight of 0.324. The A1.1. High yield production of paper criterion is the most prominent CP subcriterion under the A1. Product modification category, with a local weight of 0.654. Repair of all leaks (A3.1), creation of useful byproducts (A4.1) and engineering and educational technicians (A5.1) are regarded as the most prominent CP subcriteria in the third level under the good housekeeping (A.3), recycling (A.4) and manpower (A.5) criteria, respectively. By examining the global weight ranking of the 35 subcriteria, the top ten subcriteria for CP implementation were utilized in the Kaveh paperboard mill study (Table 4).

Table 4

Top ten subcriteria for cleaner production implementation

1	A3.1. Repair of all leaks (0.117)
2	A5.1. Engineering and educational technician (0.066)
3	A3.4. Modification and repair of dryer cylinder (0.064)
4	A5.3. Professional and technician in the CP field (0.058)
5	A1.1.1. Test line paperboard (0.047)
6	A5.2. Experienced workers (0.044)
7	A1.2. Production of unbleached instead of bleached paperboard (0.043)
8	A3.3. Removing blockage in wire and felt showers (0.042)
9	A2.1.1. Using better and standard raw material (0.040)
10	A4.2.1. Recycle steam condensed (0.036)

3.2. PRIORITIZATION OF ALTERNATIVES

After calculation of the priorities of each criterion with respect to the goal, the actual evaluation of alternatives against each criterion for all stages of the hierarchy was performed. The composite priorities of the alternatives were determined by summing the weights throughout the hierarchy. The composite priorities of the alternatives are shown in Fig. 4. The results show that the synthesis rankings with respect to the goal are water consumption (0.199), environmental pollution (0.196), raw material (0.145), solid waste (0.135), electricity (0.110), additive materials (0.108) and fuel consumption (0.107); the overall inconsistency is 0.01. According to Fig. 4, the number one priority of CP implementation in the Kaveh paper mill is reduction of water consumption.

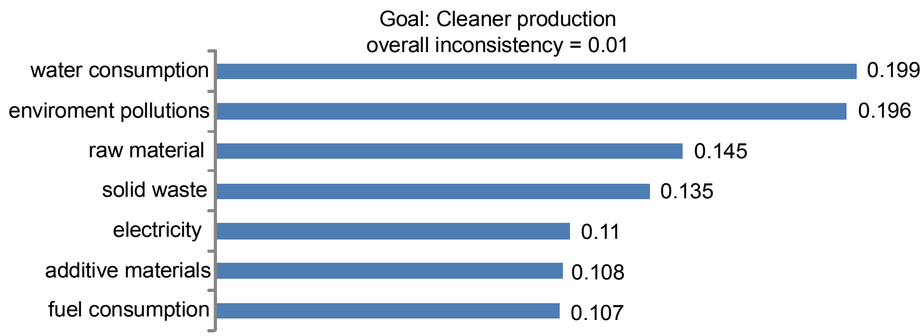

Fig. 4. Priority ranking of alternatives

4. DISCUSSION

The results of the analysis are in general agreement with those of similar projects at other pulp and paper mills. In an auditory approach conducted at SEKA Balikesir pulp and paper mill, the collected data were compared with international environmental performance indicators from other companies in the USA, Canada, Australia and Europe, emphasizing the necessity for water emission reduction [15]. The study conducted in the Delta Board Mills confirmed the importance of this alternative, indicating that the implementation of pollution prevention measures such as the recovery of fiber, reduction of fresh water consumption and optimization of white water usage proved to be very cost effective, all having short payback periods and resulting in significant savings [16]. An environmental assessment of Jordan Paper and Cardboard Factory using the waste audit tool revealed economical advantages that could be achieved in water, energy and material savings that were quantified when simple payback periods were considered for CP implementation. The authors indicated that at one site, reuse and technology change were the most efficient environmental options [17]. Incidentally, water conservation to sustain the business and also to meet future stringent statuary requirements have been discussed in detail for Century Pulp and Paper. With the goal of continual improvement in environmental performance, Nagaon Paper Mill developed a *Modernization and Technological Upgradation Plan* aimed at reduction in water consumption and wastewater discharge [18]. There are different opportunities for further reduction in water use and effluent discharge. In a comparison of Japanese and German approaches for water reduction, it was noted that, in Japan, such a theme would not attract sufficient attention from the industry. However, Germany has realized several successes due to the focus on reduced usage of paper machine water, which is easier than water reduction in pulp manufacturing. In addition, the Germany company’s positive attitude about talking to the public about their endeavor and achievement in the reduction of paper manufacturing water consumption has produced positive recognition of their efforts [19].

Table 5

Results of the sensitivity analysis (basic priority: W-E-R-S-EL-AD-F[1])

Criteria	Basic weight	Change time	New weight From	New weight To	Priority changes
Product modification	0.123	2	0.123	0.163	W-E-R-S-AD-EL-F
					W-E-R-AD-S-EL-F
Process change	0.302	4	0.302	0.277	W-E-R-S-EL-F-AD
			0.277	0.183	W-E-R-S-F-EL-AD
			0.302	0.336	W-E-R-S-AD-EL-F
			0.336	0.613	E-W-R-S-AD-EL-F
Good housekeeping	0.249	9	0.249	0.211	W-E-R-S-AD-EL-F
			0.211	0.195	E-W-R-S-AD-EL-F
			0.279	0.275	W-E-R-S-EL-F-AD
			0.275	0.388	W-E-R-S-F-EL-AD
			0.388	0.651	W-E-S-R-F-EL-AD
			0.651	0.657	W-E-S-F-R-EL-AD
			0.657	0.665	W-E-F-S-R-EL-AD
			0.665	0.761	W-E-F-S-EL-R-AD
			0.761	0.819	W-E-F-EL-S-R-AD
Recycling	0.153	5	0.158	0.118	W-E-R-S-AD-EL-F
			0.158	0.182	W-E-R-S-EL-F-AD
			0.182	0.201	E-W-R-S-EL-F-AD
			0.201	0.264	E-W-R-S-F-EL-AD
			0.264	0.805	E-W-R-F-S-EL-AD
Manpower	0.168	3	0.168	0.138	W-E-R-S-AD-EL-F
			0.130	–00	W-E-R-S-AD-F-EL
			0.168	0.469	W-E-S-R-EL-AD-F

Basic priority order is represented by: W – water consumption, E – environmental pollution, R – raw material, S – solid waste, EL – electricity, AD – additive material, and F – fuel consumption.

Process modification can reduce dependence on purchase power. It may have environmental implications at mill sites, on their product life cycle and on other interconnected systems [20]. Proper maintenance and repair of leaks has a significant role in the elimination of accidental spills and major losses of costly raw materials in industry [16]. By focusing on similar objectives in water usage and waste reduction, the Kaveh mill should realize similar positive results. Attention to the top ten subcriteria can noticeably increase energy and water savings and reduce the environmental impact via CP implementation in the Kaveh paper mill. Analyses of AHP revealed that process changes, repair of all leaks and reduction of water consumption were the most prominent criteria, subcriteria and alternatives, respectively, for the Kaveh paper mill.

Sensitivity analysis of the criteria is summarized in Table 5. According to these results, all of the criteria are sensitive, i.e., decreasing or increasing the criteria weights results in changes in prioritization. Otherwise, the study indicated that by increasing or decreasing one of the criteria, the ratios of the other criteria did not change. Sensitivity analysis is necessary in order to analyze decision making over time. Sensitivity analysis identifies the impacts of changes in the criteria priorities. We can see that there are variations in the relative importance of the criteria weights over time. Good housekeeping and recycling are more sensitive than are the other criteria. By decreasing the weight of good housekeeping, as shown in Table 5, the additives alternative (AD) is replaced by the electricity alternative (EL). In addition, increasing the weight of this criterion results in considerable change in the priority of the fuel alternative (F). Identical changes were observed for the recycling criteria. Sensitivity analysis indicated that if the Kaveh paper mill sufficiently implements CP, not only will it have a positive impact on pollution prevention and water and energy savings, but will also reduce the expenses associated with method implementation.

5. CONCLUSIONS

In this project, AHP was used to generate evaluation factors for cleaner production elements and alternatives in papermaking. Two factors, reduction of water consumption and reduction of environmental pollution streams, are the most important factors to be controlled in order to attain energy and environmental process improvement in the recycled paperboard mill. Sensitivity analysis confirms that under varying assignments of priority weights, these two factors consistently place either first or second in the analysis.

This study provided insights into sustainable development options in a recycled paperboard mill. Paper companies should consider investing in water saving, waste minimization and energy technology to reduce costs. Typically, paper mills attempt to control other process inputs, such as raw materials, additives, and fuel consumption, as these are the most visible targets in cost-containment efforts that mill staff usually focuses on. However, our work suggests that from a standpoint of cleaner production, the mill management team is better served to focus on the process changes that will impact specific outputs desired, and then try to optimize input usage according to the constraints provided by the cleaner production targets. Since, the analytic network process (ANP) is a more general form of the analytic hierarchy process (AHP), it is anticipated that this method would also be useful for assessment of energy and environmental management in the manufacturing processes which needs subsequent studies in other literatures.

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