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Multi-Criteria Decision Analysis in Planning of Asbestos-Containing Waste Management

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Abstract**—**Environmental decision making, particularly about hazardous waste management, is inherently exposed to a high potential conflict, principally because of the trade-off between socio-political, environmental, health and economic factors. The need to plan complex contexts has led to an increasing request for decision analytic techniques as support for the decision process. In this work, alternative systems of asbestos-containing waste management (ACW) in Puglia (Southern Italy) were explored by a multi-criteria decision analysis. In particular, through Analytic Hierarchy Process five alternatives management have been compared and ranked according to their performance and efficiency, taking into account environmental, health and socio-economic aspects. A separated valuation has been performed for different temporal scale. For short period results showed a narrow deviation between the disposal alternatives "mono-material landfill in public quarry" and "dedicate cells in existing landfill", with the best performance of the first one. While for long period "treatment plant to eliminate hazard from asbestos-containing waste" was prevalent, although high energy demand required to achieve the change of crystalline structure. A comparison with results from a participative approach in valuation process might be considered as future development of method application to ACW management.

Keywords**—**Multi-criteria decision analysis, Hazardous waste management, Asbestos.

I. Introduction

APULIA Regional Office and its Regional Environmental Agency (ARPA Puglia) are involved to draw up the Asbestos Waste Management Plan (AWMP). Asbestos fibers are hazardous when inhaled and can be released into the air when asbestos is incorrectly handled, stored or transported for disposal. Then, all asbestos-containing waste materials are considered hazardous wastes and must be handled and disposed in accordance with hazardous waste management procedures, as established by Council Directive 1991/689/EEC [1].

Notwithstanding the Italian law on the production prohibition of asbestos-containing materials was in 1992 [2], in Italy asbestos-containing waste management still constitutes a great problem, as before prohibition, Italy has been the major producer in Europe of asbestos-containing materials. The treatments of asbestos-containing waste (ACW) can stabilize it or modify the crystallo-chemical structure to enable its reuse. In fact, stabilization processes reduce the hazards of ACW by imprisoning asbestos fibers in inorganic or organic matrix. In this way, it can be obtained partially or totally stable materials to dispose in landfill.

On the contrary, crystallo-chemical processes change the fibrous structure of asbestos and they transform it into an inert and no-hazardous substance, allowing in most cases its reuse as new raw material. Main drawback of last treatments is high energy and resources requirements necessary to obtain high temperature conditions for the transformation of ACW crystalline structure.

The state of the art of possible treatments of ACW and its final destination [3] are reported in Table I.

TABLE I
ASBESTOS-CONTAINING WASTE TREATMENT

Treatment class	Principle	Technique	Fate
Stabilization processes	Physical	Double-bagging	Landfill
		Surface treatment	Landfill
		Encapsulation	Landfill
Crystallo-chemical process	Thermal	Vitrification	Landfill, Material for building and roadway, Tiles
		Ceramization	Landfill, Material for building and roadway, Tiles
		Pyroceramization-glass ceramization	Glass ceramic materials
		Pyrolithic lithization	Building
	Chemical	Chemical attack	Landfill
		Mechanochemical attack	Additives for cement, Catalyst

Aims and objectives of AWMP is ensuring the suitable asbestos waste management in addition to reduce occupational as well as general population exposure to asbestos. According to EU and Italian regulations this Plan as having significant effects on the environment is made subject to an

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environmental assessment, prior to its approval or authorization, on the basis of Directive 2001/42/EC (known as 'Strategic Environmental Assessment' – SEA Directive) [4].

Directive on the assessment of the effects of certain plans and programs on the environment represents a cornerstone in the environmental policy of the European Union, by setting a common procedural framework for carrying out Strategic Environmental Assessment at different levels and in virtually all sectors. The objective of Directive is to provide for a high level of protection of the environment and to promote sustainable development.

SEA is configured as a systematic process for evaluating the environmental consequences of plans and programs: it permeates the plan/program and represents a support for management and monitoring. The activities lead the dynamic management of a well-performing Strategic Environmental Assessment are: reporting and monitoring the state of the environment and its changes; encouraging the participation and opening up the discussion with stakeholders and citizens; evaluating the performance of the initiatives; testing the compliance of the decision-making process with the prevision of the plan and the achievement of the SEA; identifying and assessing the real environmental and health impacts, the cumulative effects and the sustainability of strategic initiatives.

In order to SEA methodology of preliminary Asbestos Waste Management Plan, the following main steps were envisaged: environmental baseline data analysis and scoping, scenarios building and SWOT analysis and, finally, sustainability assessment of plan's objectives, alternatives and courses of actions.

In the final version of AWMP the outcome of above steps and the participation process alike offer the negotiation of the actions Plan and produce the identification of a core set of performance indicators for monitoring Plan's implementation.

Valuation process of a environment management plan supports the decision-makers of public administration in the choice of best sustainable and fair actions on territory, but it is often cause of high conflicts among involved stakeholders (i.e. key factors, such as the authorities, local and affected people, and others). That is an inevitable situation in plural context, where any environmental problem has a lot of possible approaches, and they are not equivalent among themselves. In social choice theory, this experimented condition rests upon the Arrow's impossibility theorem. He states that "there is no consistent method by which a democratic society can make a choice that is always fair when that choice must be made from among three or more alternatives" [5]. In addition environmental is a complex social value [6], a combination of many variables interacting in no-linear and no-simple way.

In that contest, European, national and regional regulation of planning focus on fields and phases of valuation, but they don't indicate a specific decision tool. The choice is put into the hands of the decision-maker.

Therefore any possible valuation tool tries to obtain the best solution, but all decision supports have limitations which must be understood and accepted in making decision. That implies authorities must have full comprehension of the advantages and disadvantages of a specific choice. In fact a management plan is a trade-off, consisting in several actions with possible lose quality or aspect of something in return for gaining another quality or aspect.

SEA is an intrinsically multi-dimensional process. Due to this complexity, its implementation within the decision process needs decision support system [7]. The need to manage for complex contexts has led to an increasing request for decision analytic techniques as support for the decision process. Among other, multi-criteria decision analysis allows to apply scientific decision theoretical approach to complex multi-criteria problems, overcoming the shortcomings of traditional tools, such as cost-benefit or cost-effectiveness analysis.

The assessment of alternatives is often quoted as one of the basic requirements of SEA. With the aim to support scenarios building and the choice of alternatives the evaluation was carried out through an Analytical Hierarchy Process (AHP) [8] [9], where environmental, sanitary and socio-economic priorities are compared in an integrated approach.

II. Analytic Hierarchy Process

AHP is a multi-criteria decision making method helping decision-maker facing a complex problem with multiple conflicting and subjective criteria. This methodology is one of the most widely used multiple criteria decision-making tools and has been applied in very different fields [10]-[19]. The method is based on four steps:

A. structuring of the decision problem into a hierarchical model;
B. making pair -wise comparisons and obtaining the judgmental matrix;
C. local priorities and consistency of comparisons;
D. aggregation of local priorities.

Several advantages of AHP can be highlighted: AHP allows a participative, a rational, a transparent, and a traceable approach in decision-making. In fact, it takes account of several priorities and preferences, it points out the many components of issue and the reciprocal relationships, organizing them in organic way, it explains all analyzed data, and, finally, it reduces subjectivity in decision process. On the other hand it may be affected by manipulations or simplify too reality, as all models after all.

The first step of AHP is decomposition of the decision problem into elements according to their common characteristics and the formation of a hierarchical model having different levels. As above mentioned, AHP's advantage is represented by a hierarchical structure of criteria, which allows structuring the problem in a hierarchy of different levels constituting goal, criteria, sub-criteria and alternatives. Each level in the hierarchy corresponds to the common characteristic of the element in that level. The topmost level is the "goal" of the problem. The intermediate levels correspond to criteria and sub-criteria, while the lowest level contains the “decision alternatives”, as shown in Fig. 1.

Arranging the goals, attributes, issues and stakeholders in a hierarchy serves two purposes. It provides an overall view of the complex relationships inherent in the situation; and helps the decision maker assess whether the issues in each level are of the same order of magnitude, so he can compare such homogeneous element accurately. The method provides users with a better focus on specific criteria and sub-criteria when allocating the weights.

In the second step, the elements of a particular level are compared pair-wise, with respect to a specific element in the immediate upper level. First, criteria are compared pair-wise with respect to goal. A judgmental matrix, denoted as A, is formed and used for computing the priorities of the corresponding elements. Each entry a_{ij} of the judgmental matrix is formed comparing the row element a_i with the column element a_j. If the matrix is perfectly consistent, then the transitivity rule holds for all comparisons (1):

$$a_{ij} = a_{ik} \cdot a_{kj} \quad (1)$$

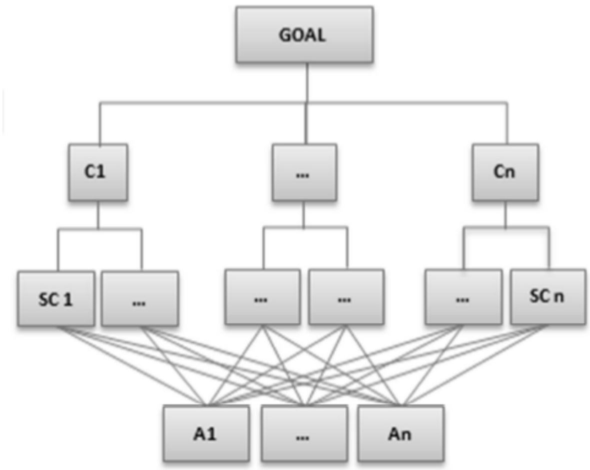

Fig.1 Hierarchical scheme of AHP (Keys: Cn=criterion; SCn=sub-criterion; An=alternative)

In the specific case of AWMP the hierarchical decision tree is been built in subsequent way: the overall objective is low impact on health, environment and socio-economic aspects. Therefore for each one of these it has been identified specific criteria of evaluation and further four/five sub-criteria are associated to every criteria of upper level.

The comparisons of any two criteria with respect to the goal made using the questions of type: “of the two criteria which is more important with respect to a low impact and much more?”. One of AHP’s strengths is the possibility to evaluate quantitative as well as qualitative criteria and alternatives on the same preference scale. To derive priorities, the verbal comparisons must be converted into numerical ones. Saaty [9] suggests the use of a 9-point scale to transform the verbal judgments into numerical quantities representing the values of a_{ij}. The scale is explained in Table II.

TABLE II
THE SEMANTIC SCALE USED IN AHP

Intensity of importance	Definition
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong Importance
6	Strong plus
7	Very strong
8	Very, very strong
9	Extreme importance

The entries a_{ij} are governed by the following rules (2):

$$a_{ij} > 0; a_{i_j} = a_{ij}^{-1}; a_{ii} = 1; \text{ for all } i \quad (2)$$

Because of these current rules, the judgmental matrix is a positive reciprocal pair-wise comparison matrix.

Once the judgmental matrix of comparisons of criteria with respect to the goal is available, in the third step the local priorities of criteria is obtained and the consistency of the judgments is determined. Priorities of criteria can be estimated by finding the principal eigenvector w of the comparison matrix A (3):

$$A \cdot w = \lambda \cdot w \quad \text{with } \lambda \text{ maximal eigenvalue} \quad (3)$$

When the vector w is normalized, it becomes the vector of priorities of the criteria with respect to the goal. λ is the maximal eigenvalue of the matrix A and the corresponding eigenvector w contains only positive entries. Normalization in the AHP enables to apportion the priority of the criterion to each alternative according to the relative dominance of the alternatives. Normalization can also be associated with the idea of scarcity and abundance of the presence of a criterion in the alternatives.

Priorities make sense only if derived from consistent or near consistent matrices. Then Saaty [20] has proposed a Consistency Index (CI), which is related to the eigenvalue method following (4):

$$CI = \frac{(\lambda_{max} - n)}{n - 1} \quad (4)$$

where n is dimension of the matrix and λ_{max} is maximal eigenvalue. The Consistency Ratio (CR) is defined as (5):

$$CR = \frac{CI}{RI} \quad (5)$$

Where RI is the Random Index equivalent to the consistency index of a randomly generated reciprocal matrix from the 9-point scale, with reciprocals forced. Saaty [20] has

The last step is to synthesize the local priorities across all criteria in order to determine the global priority, than the local priorities of elements are aggregated to obtain final priorities of the alternatives. For aggregation, local priority for each alternative *i* with respect to criterion *j* is multiplied with weight of the criterion *j*; thus, all local priorities for all criteria are added to obtain global priority of the alternative *i* and so on for every alternative. Comparisons among the scores of alternatives enable us to choose the best of them.

Finally, decision process is submitted to the sensitivity analysis, where the input data are slightly modified in order to observe the impact on the results. If the ranking doesn't changes, the results are robust, otherwise it is sensitive. In AHP the sensitivity analysis can be done on three levels: weights, local priorities and comparisons.

In the case of AWMP the hierarchical decision tree has been built in subsequent way.

In common sense, valuation refers to the contribution of an item to meeting a specific goal. Hence, it cannot attribute a value without to select the goal. In specific case the overall objective is "low impact", that is the solution that minimize impacts on environment, health and socioeconomic aspects. Then, for each one of these aspects specific criteria of evaluation have been identified and further sub-criteria have been associated to every criteria of upper level. With the aim to describe "Environment", the following criteria have been selected: atmosphere, water, land, biodiversity and landscape. "Health" has been described by noise and gaseous pollutants. Finally, "Socioeconomic factors" has been described by these criteria: resources, transports, employment, tourism, costs, system and plant management and conflicting management as result of antagonistic requests. All sub-criteria have been derived among the list of indicators developed by EEA (Environmental European Agency), according to EU's national environmental agencies.

Acting in accordance with the European Union legislative framework [21] disposal is the last one option in priority order of waste hierarchy, consequently in the specific case of asbestos-containing waste management recover must be preferred with respect to disposal in landfill. However in order to lateness piled up further a long time to reach a shared plain too, AWMP contemplates a short period solution (A options) oriented to solve as soon as possible asbestos-containing waste discharge as well as a long period outcomes (B options) with the aim to recover hazardous waste by riskiness removal in treatment plants. In addition it takes account that the implementation of a disposal solution is typically faster than the realization time of a new treatment plant. Therefore in this study the valuation of illustrated alternatives of asbestos-containing waste management has been performed in two independent and sequential steps. The former aims to define the best alternative to dispose waste. Then, the selected disposal option was considered in the latter step.

provided average consistencies (RI values) of randomly matrices of different sizes. If CR is less than 10% then the matrix can be considered as having an acceptable consistency.

In AWMP the B options are referred as two different type of ACW treatments without defining a specific solution for plant technology, by taking into account the final degree of danger achieved with the recovery treatment. Accordance with European Directive 1999/31/CE [22] the one options include also preliminary packaging by double-bagging.

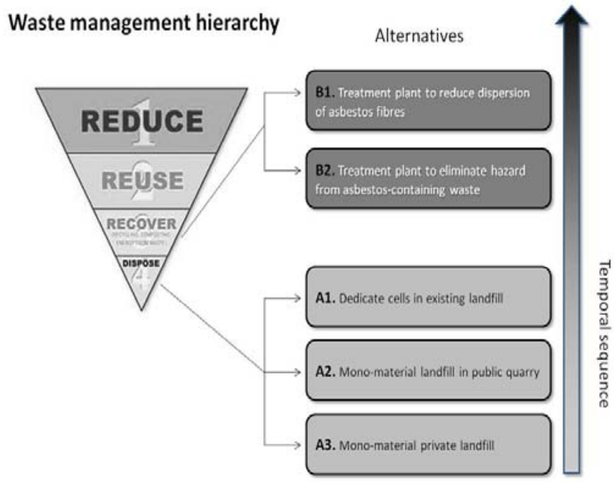

Fig. 2 The temporal sequence of AWMP alternatives in relation to European waste management hierarchy

III. Results

Table III shows the AHP hierarchy. Since the five alternatives, three for short period and two for long period, are evaluated at lowest level for all criteria, they are present at the bottom of the hierarchy. At the top of hierarchy is the overall goal of low impact solution for managing the asbestos-contain waste in Southern Italy. Three criteria are identified as essential for achieving the overall goal: environmental, sanitary, and social-economical.

The environmental criterion is further divided into five sub-criteria aimed at environmental maximum protection: atmosphere, water, land, biodiversity and landscape.

There are two sanitary considerations, which are related to the effect of noise and gaseous pollutants. The noise category is further divided into impact on people and impact increasing. The goal of Noise criterion is to minimize the annoyance related to the treatment/disposal plants of the considered wastes. The goal of Gaseous pollutants is to minimize it. This category is divided into micro-pollutants, macro-pollutants and fog formation.

Given goal, when criteria and sub-criteria are fixed, it is required to allocate the size of each element, according to the importance of the elements. In an evaluation process oriented to obtain the decision more sustainable and shared by citizens and stakeholders, the elements of the hierarchical structure must also be weighted.

TABLE III
AHP HIERARCHY LOCAL PRIORITIES

Goal (level 1)	Criterion (level 2)	Criterion (level 3)	Sub-criterion (level 4)	Alternative
		Atmosphere **[0.200]**	Air Quality **[0.250]** Green-House Gas Emissions **[0.250]** Thermal Load **[0.250]** Industrial Gas Emissions **[0.250]**	
		Water **[0.200]**	Water consumption **[0,459]** Liquid waste **[0,304]** Interaction with water network **[0,079]** Interaction with aquifer **[0,079]** Flooding **[0,079]**	
	Environment **[0,143]**	Land **[0.200]**	Land consumption **[0,503]** Sludge and waste **[0,382]** Interaction with seismic areas **[0,057]** Interaction with landslide and sinkhole areas **[0,057]**	SHORT PERIOD A1 dedicate cells in existing landfill
		Biodiversity **[0.200]**	Flora **[0,500]** Fauna **[0,500]**	A2 mono-material landfill in public quarry
		Landscape **[0.200]**	Plant shutdown **[0,591]** Plant **[0,333]** Plume **[0,075]**	A3 mono-material private landfill
Low impact		Noise **[0.200]**	Impact on people **[0,833]** Impact increasing **[0,167]**	
	Health **[0,714]**	Gaseous pollutants **[0.200]**	Micro-pollutants **[0,591]** Macro-pollutants **[0,333]** Fog formation **[0,075]**	LONG PERIOD B1 treatment plant to reduce dispersion of asbestos fibers
		Resources **[0.200]**	Energy/resources consumption **[1,00]**	
		Transport **[0.200]**	Proximity principle **[0,633]** Gas emission **[0,302]** Interaction with vehicle fleet **[0,065]**	B2 treatment plant to eliminate hazard from asbestos-containing waste
		Occupation **[0.200]**	Running **[0,800]** Building **[0,200]**	
	Society- Economy **[0,143]**	Tourism **[0.200]**	Presences/arrivals **[1,00]**	
		Cost **[0.200]**	Disposal/treatment **[0,778]** Running **[0,111]** Building **[0,111]**	
		Management **[0.200]**	Type (public/private) **[0,250]** Beginning in operation **[0,250]** Dimensional flexibility **[0,250]** Management hierarchy**[0,250]**	
		Risk perception **[0.200]**	Social conflicts **[0,250]**	

Faced with the problem of weighting, decision makers are often embarrassed. So in the specific case of AWMP this weighting takes account of the requirements resulting from public participation, considers human health as a priority and assures the legislation accordance.

Through the Analytic Hierarchy Process method the multi-criteria weighting of a set of various criteria has been decomposed into several steps of mono criterion weighting. With respect to criteria on level 2, "Health" is the criterion with more importance, so its weight is higher than weights allocated to criteria "Environment" and "Society-Economy". At level 3 the same weights are assigned for each one criterion because of all criteria of level 3 concur to describe the corresponding criterion at level 2 in the same way. Finally, at level 4 the weighting process of every sub-criterion is different and changes in relation to importance and relevance of each indicator related to its upper criterion.

The local priorities of criteria and sub-criteria for the short and long term have been assessed and reported in Table III. The local priorities of alternatives for the short and long term have been assessed and have been reported three peculiar examples in Tables IV, V and VI.

Considering environmental criterion, the local priorities of alternatives respect to the sub-criterion “land” have been shown in Table IV. The higher soil consumption could be determined by adopting A3 alternative, furthermore A1 alternative could cause a higher consumption of soil compared to A2. The management of A3 alternative is delegated to private, so the location of the plant may not be a pre-existing quarry. The environmentally worst case has been considered in this assessment. Due to digging operations needed to make plant, A3 represents the scenario more impactful related to soil consumption. An expansion of the existing landfill (A1) or a construction of new plant (A3) produce waste as soil and rock by excavation. A3 could lead to more waste than A1 and A2. Given the unpredictability of earthquakes, and considering that the influence area of each seismic event could include the entire region, as a precautionary measure, equal weight has been attributed at alternatives (A1, A2, A3) relating to likelihood of damage the volume of asbestos-containing waste during a seismic event. The alternative A1 involves a minor interference with unstable areas than A2 and A3, as the dedicated cells being arranged in existing landfills where it is expected that any excavation in unstable area have already been secured.

Both treatment plants B1 and B2 determine similar regarding land consumption, interaction with seismic and with landslide and sinkhole areas, since the industrial plants have similar waterproof areas and are subjected to similar regulatory criteria for their location. However, the B1 option providing the final disposal in landfill of treated waste, will lead to greater environmental impact than B2 in relation to the sub-criterion “sludge and other waste” connected to the system.

Considering health criterion, the local priorities of alternatives respect to the sub-criterion “gaseous pollutants” have been shown in Table V. At disposal plants do not apply the Macro-pollutants, Micro-pollutants and Fog formation sub-criteria, as they are not based on the combustion process. Then, the three alternatives in the short period have the same health scores as they are based on the same processes. For long period, not being defined in planning a specific type of technology to be used, nor excluding that in the future, during the validity of the Plan, could be developed for new, the evaluations have been based on general considerations. Even though the alternative B1 has the best score in terms of micro-pollutant emissions, the preferred alternative is B2, as by transforming the crystal structure of asbestos fibers it eliminates the health risk.

Considering the society-economy criterion, the local priorities of alternatives respect to the sub-criterion “management” have been reported in Table VI. "Dimensional flexibility" sub-criterion is only applicable to landfills and in particular, indicates the possibility to cultivate landfill for subsequent steps, as to follow the trend of waste production.

The criterion of "management hierarchy", however, is only applicable to the treatment plants, since the alternatives regarding landfills may provide only the disposal. The public type management is preferable to private one because, through it, could be achieved a minors final costs of disposal. “Beginning operation” sub- criterion depends on the magnitude of plant to be executed and on the time needed for obtaining licenses to perform activities.

The A1 alternative has the lowest time of “Beginning operation”, since it would be realized as expansion / upgrading of existing plants. For the same reason, the cells are also characterized by greater dimensional flexibility than A3, since the lots may be authorized and implemented in succession, according to the real requirements of waste volume. In terms of dimensional flexibility the A2 alternative is preferable respect to the others. Alternative A2 is linked to the public manage, so it ensures the achievement of plant, which in other alternatives depend exclusively on the private sector, linked to the market rather than planning choices. For long period, there are not planned public plants and also the “dimensional flexibility” criterion is not applicable. Both types of systems are characterized by “beginning in operation” very long, especially, being still experimental and non-consolidated technologies with high costs. In this assessment the main difference between alternatives is the hierarchy of waste management.

For B1 alternative, the product of treatment is itself a waste characterized by a less dangerous, so as to ensure its entry into a landfill for non-hazardous waste. Considering management hierarchy, as introduced by European Directive 2008/98 EC, the recovery has priority on disposal. Consequently, the B2 alternative by operating on chemical modification of asbestos molecules turns it into a reusable material as inert.

TABLE IV
LOCAL PRIORITIES OF LAND SUB-CRITERIA ALTERNATIVES

Criterion (level 3)	Sub-criterion (level 4)	Alternative (short period) A1	A2	A3	Alternative (long period) B1	B2
Land **[0.200]**	Land consumption [0,503]	0,262	0,682	0,056	0,500	0,500
	Sludge and waste [0,382]	0,311	0,599	0,090	0,250	0,750
	Interaction with seismic areas [0,057]	0,333	0,333	0,333	0,500	0,500
	Interaction with landslide and sinkhole areas [0,057]	0,574	0,180	0,246	0,500	0,500

TABLE V
LOCAL PRIORITIES OF GASEOUS POLLUTANTS SUB-CRITERIA ALTERNATIVES

Criterion (level 3)	Sub-criterion (level 4)	Alternative (short period) A1	A2	A3	Alternative (long period) B1	B2
Gaseous pollutants **[0.200]**	Micro-pollutants [0,591]	0,333	0,333	0,333	0,111	0,889
	Macro-pollutants [0,333]	0,333	0,333	0,333	0,750	0,250
	Fog formation [0,075]	0,333	0,333	0,333	0,500	0,500

TABLE VI
LOCAL PRIORITIES OF MANAGEMENT SUB-CRITERIA ALTERNATIVES

Criterion (level 3)	Sub-criterion (level 4)	Alternative (short period) A1	A2	A3	Alternative (long period) B1	B2
Management **[0.200]**	Type (public/private) [0,250]	0,100	0,800	0,100	0,500	0,500
	Beginning in operation [0,250]	0,623	0,295	0,082	0,500	0,500
	Dimensional flexibility [0,250]	0,319	0,612	0,069	0,500	0,500
	Management hierarchy[0,250]	0,333	0,333	0,333	0,111	0,889

TABLE VII
PRIORITY VECTORS OF ALTERNATIVES

Alternative	Description	Local priority Environment	Health	Social- Economy	Global priority
A1	Dedicate cells in existing landfill	0,052	0,253	0,063	0,368
A2	Mono-material landfill in public quarry	0,070	0,247	0,060	0,378
A3	Mono-material private landfill	0,021	0,214	0,023	0,258
B1	Treatment plant to reduce dispersion of asbestos fibres	0,079	0,265	0,059	0,403
B2	Treatment plant to eliminate hazard from asbestos-containing waste	0,056	0,346	0,084	0,485

From hierarchical reconstruction, the global priorities related to goal (low impact) have been obtained and the preferable alternative for short and long period has been determined (Table VII).

For planned short period, the final result shows that, although there is not a large gap between the scores related to the analyzed three alternative, the disposal solution “mono-material landfill in public quarry” guarantees the best global performance. From the environmental point of view the first two alternatives (A1 and A2) provide better performance than the third (A3; Tab. VII). This result highlight the context in which the alternative A1 and A2 will be inserted, in fact, in both cases, the environmental setting is already modified and then subjected to continuous monitoring and control. In particular, the inclusion of mono-material landfills in public quarries avoids a further soil consumption, and does not bring further imbalances in the hydrological and hydrogeological regime. For the reasons stated above, also the impact on the landscape is attenuated by including plant in anthropically affected areas. Regarding health criterion, the first alternative (A1) has a score slightly higher than the other two, due to the sub-criterion “noise”. In particular, considering the increased noise on the receptors, the cells dedicated in existing landfills are preferred over other solutions as it will not produce a big changes compared to existed plants. Regarding socio-economic perspective, mono-material landfill in public quarry detects the best performance because of their public management that could lead to a considerable reduction in the cost of waste disposal and could allow a flexible cultivation. The dimensional flexibility is due to the pre-existing volumes already available, which would allow to cultivate by steps in relation to the real waste mobilized by planned actions. From the Saaty's hierarchical approach the alternative A2 appears to be able to minimize the environmental and sanitary impact and maximize socio-economic benefits.

For long period, the comparative assessment developed with the hierarchical analysis shows that, while not registering significant differences in the scores, the treatment plants with modification of the microcrystalline structure (B2) provide the best overall performance. From the environmental point of view, however, treatment plant to reduce dispersion of asbestos fibers (B1) has a better performance than the other type. This result depends on the very high energy demand required to achieve the high temperatures during the transformation processes. Although in the planning, the use of alternative fuels (such as biomass or waste) is considered as mitigation, this alternative implies, however, a low performance for sub-criterion "atmosphere". For the sanitary criterion, the treatment type B2 has the best performance despite the production of macro-pollutants by combustion processes. In fact, elimination of hazard related to dispersion in the atmosphere of asbestos fibers is considered much important, in terms of health protection, than production of macro-pollutants. Also with regard to the Considering socio-economic criterion, alternative B2 has the best performance due to low costs of disposal / treatment (no need to disposal), to higher rank in the hierarchy of management and to lower risk perception by population. Finally by comparison, the alternative B2 results the preferable.

IV. Conclusion

The illustrated application of AHP confirms well-known advantages of this methodology.

AHP has broken through the academic community to be widely used by practitioners. This widespread use is certainly due to its ease of applicability and the structure of AHP which follows the intuitive way in which managers solve problems. The hierarchal modeling of the problem, the possibility to adopt verbal judgments and the verification of the consistency are its major assets. In addition to its ease, versatility, and accuracy, it allows to suitably aggregating in a common valuation process judgments of experts in very different fields. Finally AHP is flexible to be integrated with different techniques, as Linear Programming, Fuzzy Logic, etc., reaching better results by maximize all benefits of methods.

Considering the relevance of participative approach in plane valuation, the assignation of priorities among several impacts by involving local citizens and stakeholders [23] can be considered as next development of the application of AHP to AWMP. They may be consulted via questionnaire to capture their perception on the relative importance of possible impacts and in thus to identify the best mitigation and compensation actions in order to minimize potential social conflicts.

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