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Francesca Abastante*

Department of Regional and Urban Studies and Planning (DIST),
Politecnico di Torino,
Turin, Italy
Email: francesca.abastante@polito.it
*Corresponding author

Salvatore Corrente

Department of Economics and Business,
University of Catania, Italy
Email: salvatore.corrente@unict.it

Salvatore Greco

Department of Economics and Business,
University of Catania, Italy
and
CORL, Portsmouth Business School,
University of Portsmouth, UK
Email: salgreco@unict.it

Isabella M. Lami

Department of Regional and Urban Studies and Planning (DIST),
Politecnico di Torino,
Turin, Italy
Email: isabella.lami@politecnico.it

Abstract: How to handle an environmental/urban decision problem with many alternatives and the presence of several interdependent criteria? Starting from the 'Futur-e Project' of the main Italian distributor of electricity, the paper proposes an integrated MCDA approach illustrated by the comparison of alternative projects for the reuse of a large abandoned thermoelectric power plant in Italy. We focus on the following aspects: 1) evaluation of the feasible plan performances with respect to criteria; 2) construction of a reliable decision support model requiring the decision-maker parsimonious preference information. We adopted an assessment framework based on the Choquet integral to represent interaction between criteria, parsimonious AHP reducing the number of pairwise comparisons, and SMAA permitting to explore the space of different recommendations supplied by the decision model in case of perturbation of its parameters. We report on the evolution of the procedure and on the aspects of the support provided by the adopted approach.

Keywords: adaptive reuse; analytic hierarchy process; AHP; Choquet integral; stochastic multicriteria acceptability analysis; SMAA; remediation of contaminated sites; multiple criteria decision aiding; MCDA; interacting criteria.

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Biographical notes: Francesca Abastante received her PhD in Regional and Urban Studies. She is currently a researcher with the Interuniversity Department of Regional and Urban Studies and Planning of Politecnico and Università di Torino (DIST), Italy. She is a member of numerous national and international research projects and her research focuses on studies related to multicriteria decision making and decision processes in territorial projects with the attention to financial analysis and visual tools to support real-time decision processes through the in-depth study of sustainability assessment tools. She is a member of the PhD Board 'Urban and Regional Development' at the Politecnico di Torino.

Salvatore Corrente received his Master's degree in Mathematics in 2008 and PhD in Pure and Applied Mathematics in 2016 from the Department of Mathematics and Computer Science of the University of Catania. He is an Associate Professor at the Department of Economics and Business of the University of Catania. His research interests concern multiple criteria decision making and interactive evolutionary multi-objective optimisation. He received the Bernard Roy Award 2020 for his contribution to multicriteria decision aiding methodology from the European Working Group on Multiple Criteria Decision Aiding.

Salvatore Greco is a Professor at the Department of Economics, Catania University and a part time Professor at the University of Portsmouth. He has been invited professor at many universities among which Poznan Technical University and University of Paris Dauphine. His research interests concern decision theory, multiple criteria decision making, composite indicators, decisions under uncertainty and dominance based rough set approach. He is the President of the INFORMS MCDM Section and coordinator of the EWG on MCDA. He received the Gold Medal of the MCDM International Society in 2013.

Isabella M. Lami graduated with honours in Architecture. She has a PhD in Real Estate and Urban Planning and MSc in Real Estate and Urban Planning. She is a Professor of Urban Planning Evaluation and Project Appraisal at the Interuniversity Department of Regional and Urban Studies and Planning of Politecnico and Università di Torino (DIST), Italy. She is a member of the PhD Board 'Urban and Regional Development' at the Politecnico di Torino. She has extensive experience in multicriteria decision analysis (MCDA), problem structuring methods and decision-making processes in the context of urban and territorial transformations, as well as in the management of participatory processes.

1 Introduction

The starting point of this paper is a profound transformation of the entire energy system currently underway in Italy. In fact, while until some years ago few large power plants produced energy for the whole country, today, small, renewable plants, widespread throughout Italy, are giving shape to a new, more distributed model of energy generation.

This is framed in a radical change in the concept of energy production following the energy and ecological transition (Nieto et al., 2020; Rotondo et al., 2020) which aims at guiding towards sustainable and efficient production models. The profound modification in energy production technologies is reflected in changes in urban areas with reference to the abandonment of large portions of land once used for energy production. Consequently, the need to recover and enhance the buildings is emerging with respect to areas which:

1. are often located in territories in economic crisis, whose transformation is vague in its definition and urban planning guidelines
2. are requiring a masterplan definition comparable to the design of a new district for the city
3. are characterised by land pollution
4. need for alternative functional mixes.

The aim of this paper is to develop and test an assessment methodology capable of supporting a complex decision-making process such as the identification of the best alternatives of intervention for the redevelopment of Brownfield areas that used to host energy production. This paper aims at different levels of deterioration without precise indications with respect to the transformation to be carried out?

In addressing the problem, the study had to consider the huge number of alternatives and decision criteria to be evaluated and compared, the heterogeneous nature of quantitative and qualitative decision criteria and the interdependence of the criteria. In this perspective, the ‘architecture choice’ (Thaler and Sunstein, 2008; Abastante et al., 2012, 2018) required a specific attention to effectively handle this peculiar environmental, economic and urban problem. More precisely and more technically, we propose a multiple criteria decision aiding (MCDA) (Greco et al., 2016) assessment framework based on

- The analytic hierarchy process (AHP)-Choquet method (Corrente et al., 2016), to consider the interaction between criteria.
- The parsimonious AHP method (Abastante et al., 2019) to reduce, with respect to the standard AHP method (Saaty, 1980), the number of pairwise judgements required to the DM with the aim of constructing a common scale for all criteria.
- The stochastic multicriteria acceptability analysis (SMAA) (Lahdelma et al., 1998; Pelissari et al., 2020), applied to the Choquet integral (Angilella et al., 2015), to consider robustness concerns related to variability of the results provided by the decision model in the space of preference parameters compatible with preference expressed by the DM.

To properly develop and test the methodology, the present research moves from a national project launched by the main Italian distributor of electricity (ENEL). The project is called 'Futur-e' and aims at rethinking the future of 24 abandoned thermoelectric power plants (http://corporate.enel.it/en/future). We take into consideration the former thermoelectric power plant located in Bari (South of Italy), as a demonstration of the possible problems that can be encountered in discussing the transformation of a former power plant.

In details, the reasons for which we considered this Brownfield as a perfect case study for identifying a suitable methodology to support the complex decisional process are several:

1. The huge dimension of the area allowed us to develop a comprehensive conceptual framework in terms of urban planning, design and remediation of contaminated soils.
2. The variety of intervention proposals permitted to define structured plans by combining into functional mixes elementary proposals.
3. The strategic position of the area in terms of accessibility and proximity to the city centre constitutes an opportunity for an urban and social relaunch of the neighbourhood which goes well beyond the mere formulation of the decision problems in terms of urbanistic design.

Therefore, this case study is extreme in its possibilities: a 'combinatorial explosion' of potential mixes of diversified uses is considered, with the risk of significantly aggravating the cognitive effort of the DM.

This application has been conducted during a high-level university program involving two universities in Italy (Politecnico di Torino and Politecnico di Milano) with the support of ENEL, who acted as a DM. Although in the form of a 'laboratory simulation', the decision situation considered in the paper can be seen as a test to verify, in a plausible and realistic context, the effectiveness of a decision procedure.

The structure of the paper is the following. Section 2 presents the main characteristics of the applied framework underlying its main points in comparison with other approaches used in literature to deal with the same issues. The theoretical aspects of the methodological framework are here synthetically illustrated. Section 3 shows the comparison of 19 alternative requalification projects for the reuse of an abandoned thermoelectric power plant. The valuation process and the results are further discussed in Section 4, while conclusions are drawn in Section 5.

2 Characteristics of the applied decision method and its main steps

In MCDA a set of alternatives is generally evaluated based on a set of criteria to deal with choice, ranking or sorting problems (Greco et al., 2016). Several methods have been developed along the years to handle such problems and four issues are nowadays common in decision problems:

1. Heterogeneity of considered criteria. The criteria considered in the decision analysis are, in general, not expressed on the same unit scale. Because the use of compensatory methods such as the weighted sum or the Choquet integral requires that all evaluations are expressed on the same scale, it is necessary to perform a

normalisation or standardisation of the data. However, different types of normalisation have been proposed (Massam, 1988) and each of them influences the final recommendation without considering any preference of the DM. The framework we are applying in this paper performs a normalisation of the alternatives' evaluations using the AHP that will be briefly recalled in Section 2.1. Its use permits to put all evaluations on the same scale considering also the preferences of the DM on the single criteria. Indeed, while normalisation techniques are strictly dependent on the numerical evaluations of the alternatives on the criteria, AHP permits the DM to obtain a normalised evaluation based on DM's preferences expressed in terms of pairwise judgements on the alternatives considered in the decision problem at hand. For example, while a min-max normalisation would transform a certain evaluation x in the evaluation x' in an aseptic way independently on the DM who has to take the decision, the same evaluation x can have a different meaning depending on the DM. AHP, by means of pairwise comparison between performances on the criterion at hand, permits to consider DM's preferences.

2 Interaction between criteria. Some criteria considered in a decision problem are not necessarily independent, but they can present a certain level of negative or positive interaction. On one hand, two criteria are negatively interacting if the importance assigned to both together is lower than the sum of the importance assigned to them singularly, while, on the other hand, they are positively interacting if the importance given to them together is greater than the sum of the importance assigned to them, singularly.

In this paper, to consider interactions between criteria, the Choquet integral is used being the most adopted aggregation procedure used in literature to handle interacting criteria in compensatory multi-attribute evaluation problems. Let us remember that to handle interacting criteria in non-compensatory approaches, different methods have been recently proposed to construct binary outranking relations considering redundancy or synergy between criteria. In this perspective we recall ELECTRE with interactions (Figueira et al., 2009) and PROMETHEE with interactions (Arcidiacono et al., 2018). These outranking approaches for interacting criteria are very interesting and useful in decision support. However, since we are interested into assigning an evaluation to each alternative, in this paper we consider the Choquet integral, which has also the advantage of being simpler than outranking methods for interacting criteria. This simplicity is an important aspect to take into account in designing a decision support procedure. Indeed, decision support methods must be evaluated not only for their capability to consider specific and delicate aspects of DM's preferences, but also for their capability to provide simple explanations of the same preferences and, consequently, of the final recommendation they supply to the DM. In fact, we can say that the simplest the model, the better it is (Arcidiacono et al., 2020). From this point of view, one can observe that the weighted sum is the most used method applied in practice in consequence of its simplicity and the Choquet integral is its most direct generalisation since it boils down to the weighted sum if there is not any interaction between criteria. Consequently, looking for simplicity of the methodology, the adoption of the Choquet integral seems very appropriate in case of interaction of criteria. In addition, observe that, if necessary, it is also possible to consider interactions between criteria in a parsimonious way

(Arcidiacono et al., 2021), that is, avoiding to include parameters not necessary to explain the preferences given by the DM.

3 Robustness of the recommendations provided by the adopted method. The use of all MCDA methods is based on the knowledge of some parameters. For example, to use the weighted sum, the importance of each criterion has to be considered, while to use the Choquet integral, in addition to the importance of each criterion, the importance of each subset of criteria should be considered. However, the DM could fill upset with a direct elicitation technique requiring her to provide exact values to these parameters, firstly, because of its huge number and, secondly, because it can be difficult for her giving a real meaning to them. For this reason, an indirect elicitation technique is used in this paper. In using the indirect elicitation technique, the DM is invited to provide a preference information in terms of comparison between alternatives (alternative *a* is preferred to alternative *b*), comparison between criteria (criterion *i* is more important than criterion *j*) or interaction between criteria (criteria *i* and *j* are positively or negatively interacting). Then, decision model parameters compatible with this preference information are inferred by solving linear programming problems.

Even if the use of an indirect elicitation technique makes easier the use of the Choquet integral, another problem arises due to the lack of robustness into providing a recommendation using a single vector of parameters compatible with the preferences provided by the DM. Indeed, several vectors of parameters could be compatible with the preference information expressed by the DM and the application of the Choquet integral considering each of them could provide different recommendations on the considered problem. For such a reason, the use of a single vector of parameters can be considered misleading and the necessity to consider all of them arises. The method applied in this paper will solve this problem by using the SMAA methodology that will be briefly recalled in Section 2.2. SMAA gives recommendations in statistical terms based on the whole set of vectors of parameters compatible with the preferences provided by the DM avoiding, therefore, to choose only one of them.

4 High or even very high number of alternatives to deal with. The consideration of a large or even very large number of alternatives is linked to point (*i*) described above. Indeed, if the AHP can be used to normalise the data considering the preferences of the DM, it can difficulty be used in case the number of alternatives is high since it requires one pairwise comparison for each pair of alternatives. For example, in a not so big problem regarding eight alternatives and seven criteria, the DM would be asked to provide 196 comparisons to put all evaluations on the same scale. However, this is quite demanding for the DM from a cognitive point of view. For such a reason, in this paper we applied a parsimonious version of the AHP method recently proposed in literature (Corrente et al., 2016; Abastante et al., 2019), that involves a lower cognitive effort from the part of the DM who has not to pairwise compare all alternatives on each criterion but only some reference alternatives that are fixed from the analyst with the involvement of the DM herself. In this way, we can use the great potentialities of the AHP method also to deal with decision problems involving a huge number of alternatives being an important component of nowadays decision problems (Maghsoodi et al., 2020).

The methodologies used to tackle the aforementioned four issues are reported in the next sections.

2.1 The parsimonious AHP

The AHP (Saaty, 1980) is one of the most well-known and applied MCDA methods to deal with a decision-making problem. It aims to build a ratio scale between different levels of alternatives or importance of criteria based on some preference information provided by the DM. For illustrative reasons, in the following we shall describe the application of AHP to associate a priority to each alternative so that all alternatives' evaluations are expressed on the same scale. Let us consider a problem in which n alternatives are evaluated on m evaluation criteria $G = \{g_1, \ldots, g_m\}$ and let us assume that each alternative a_i is associated with a priority w_i. To find such priorities, the DM has to fill in a matrix $A = [a_{ii'}]_{i,i' = 1, \ldots, n}$ where, in this case, each element $a_{ii'}$ represents how many times alternative a_i is more preferable than alternative $a_{i'}$. Such preference has to be expressed on a 1–9 verbal scale where 1 means that a_i and $a_{i'}$ are equally preferable, 3 that a_i is moderately more preferable than $a_{i'}$ and so on, until 9 meaning that a_i is strongly more preferable than $a_{i'}$. Each value $a_{ii'}$ is therefore considered as an estimate of the ratio between the priority of a_i and the priority of $a_{i'}$, that is, $\frac{w_i}{w_i'}$. A is a reciprocal matrix, that is, $a_{ii'} = \frac{1}{a_{i'i}}$ for each $i, i' = 1, \ldots, n$ and, if it is perfectly consistent, then $a_{ii'} = a_{ik} \cdot a_{ki'}$ for all $i, k, i' = 1, \ldots, n$. Several methods have been proposed to infer the values of w_i on the basis of the information included in A (Crawford and Williams, 1985; Siraj et al., 2012; Tsyganok, 2010) but the most applied is the right eigenvector method (Saaty, 1977) in which the priorities vector $(w_1, \ldots, w_n)$ can be approximated by the right eigenvector $(p_1, \ldots, p_n)$ associated to the maximal eigenvalue $\lambda_{\max}$, of A.

Since the information provided by the DM, in general, is not perfectly consistent, the consistency ratio of A is computed as $CR = \frac{CI}{RI}$ where $CI = \frac{\lambda_{\max} - n}{n-1}$ is the consistency index of A and RI is the ratio index computed as the average CI of 500 randomly generated reciprocal matrices of order n. If $CR < 0.1$, the preferences provided by the DM are retained consistent enough. AHP has to be applied once for each criterion to find the priorities of the considered alternatives on the criteria at hand. To make them comparable, the priorities obtained by AHP $(p_1, \ldots, p_n)$ are therefore normalised to obtain a vector of normalised priorities $(\overline{p}_1, \ldots, \overline{p}_n)$ so that $\overline{p}_i = \frac{p_i}{\max\limits_{i=1,\ldots n} p_i}$.

The application of the AHP could be difficult for the DM if many alternatives have to be considered since she is asked to express a preference for each pair of alternatives. For such a reason, in this paper we shall apply an improvement of the AHP that has been recently introduced in literature by Corrente et al. (2016) and Abastante et al. (2019) to make easier its application in such a case. The procedure is composed of the following steps:

1 For each criterion g_j, a set of t_j reference points $R_j = \{\gamma_{j1}, ..., \gamma_{jt_j}\}$, meaningful for the DM and well distributed on the evaluation scale of g_j, has to be defined.

2 For each criterion g_j, AHP is applied to the set of reference points R_j to get the priorities $(\overline{p}_{j1}, ..., \overline{p}_{jt_j})$.

3 For each criterion g_j and for each alternative $a_i \in A$, the priority of the evaluation of a_i on g_j, that is $u(g_j(a_i))$ is obtained by interpolating the values $(\overline{p}_{j1}, ..., \overline{p}_{jt_j})$ found on the previous point. If $g_j(a_i)) \in [\overline{p}_{js}, \overline{p}_{j(s+1)}]$, with $s = 1,\ldots, t_j - 1$, then

$$u\left(g_j\left(a_i\right)\right) = \overline{p}_{js} + \frac{\overline{p}_{j(s+1)} - \overline{p}_{js}}{\gamma_{j(s+1)} - \gamma_{js}}\left(g_j\left(a_i\right) - \gamma_{js}\right). \tag{1}$$

2.2 Definition of the interactions between the criteria: the Choquet integral preference model

Given a set of n alternatives $A = \{a_1, \ldots, a_n\}$ evaluated on m evaluation criteria $G = \{g_1, \ldots, g_m\}$, the weighted sum

$$U\left(a_i\right) = \sum_{j=1}^{m} w_j \cdot g_j\left(a_i\right) \tag{2}$$

Is in general, the most used preference model to aggregate the alternative's evaluations $(g_1(a_i), \ldots, g_m(a_i))$. In equation (2), w_j represents the importance of criterion g_j and it is such that $w_j > 0$ for all $j = 1,\ldots, m$ and $\sum_{j=1}^{m} w_j = 1.$

The use of a weighted sum implies that the set of criteria is mutually preferentially independent (Keeney and Raiffa, 1976; Wakker, 1989). However, in real world applications this is a quite strict assumption since criteria at hand can present a certain degree of positive or negative interaction. On the one hand, two criteria g_j and g_j' are positively interacting if the importance assigned to them together is greater than the sum of their importance considered singularly, while, on the other hand, they are negatively interacting if the importance assigned to them together is lower than the sum of their importance when considered singularly. To consider such type of interactions, in literature non-additive integrals are used (Grabisch and Labreuche, 2010) and the most applied of them is the Choquet integral preference model (Choquet, 1953; Grabisch, 1996).

The Choquet integral is based on a capacity μ: $2^G \to R$, that is a set function assigning a value to each subset of criteria in G so that normalisation ($\mu(\emptyset) = 0$ and $\mu(G) = 1$) and monotonicity ($\mu(B) \leq \mu(C)$ for all $B \subseteq C \subseteq G$) constraints are satisfied. The application of the Choquet integral involves, therefore, the knowledge of $2^n - 2$ values. To make things easier, a Möbius transformation of the capacity μ (Rota, 1964) and k-additive capacities (Grabisch, 1997) are used:

- The Möbius transformation of μ is a set function m: $2^G \to R$ such that for each subset of criteria $B \subseteq G$, $\mu(B) = \Sigma_{T \subseteq B}\, m(T)$.

- A capacity μ is said k-additive if its Möbius transformation m is such that $m(T) = 0$ for all $T \subseteq G$ such that $|T| > k$.

In general, 2-additive capacities are enough to represent the preferences provided by the DM. Considering a 2-additive capacity, the Choquet integral of $(g_1(a_i), \ldots, g_m(a_i))$ (for brevity, the Choquet integral of a_i in the following), is computed as follows:

$$Ch_\mu(a_i) = \sum_{j=1}^{m} g_j(a_i) \cdot m(\{g_j\}) + \sum_{\{g_j, g_{j'}\} \subseteq G}^{m} \min\{g_j(a_i), g_{j'}(a_i)\} \cdot m(\{g_j, g_{j'}\}) \tag{3}$$

While the normalisation and monotonicity constraints are rewritten as

$$\begin{cases} m(\{g_j\}) \geq 0 & \\ m(\{g_j\}) + \sum_{g_{j'} \in T}^{m} m(\{g_j, g_{j'}\}) \geq 0 & \text{for all } g_j \in G \\ m(\varnothing) = 0 & \\ \sum_{g_j \in G}^{m} m(\{g_j\}) + \sum_{\{g_j, g_{j'}\} \subseteq G}^{m} m(\{g_j, g_{j'}\}) = 1. & \text{for all } g_j \in G \text{ and for all } T \subseteq G \setminus \{g_j\} \end{cases}$$

In such a context, the importance of a criterion g_j is dependent not only on itself but also on its contribution to all possible coalitions of criteria. For such a reason, in case 2-additive capacities are used, the Shapley index $\varphi(\{g_j\})$ (Shapley, 1953) representing the importance of a criterion g_j and the interaction index $\varphi(\{g_j, g_{j'}\})$ (Murofushi and Soneda, 1993) representing the importance of a pair of criteria $\{g_j, g_{j'}\}$ are computed in the following way:

$$\varphi(g_j) = m(\{g_j\}) + \sum_{g_{j'} \in G \setminus \{g_j\}} \frac{m(\{g_j, g_{j'}\})}{2};$$

$$\varphi(\{g_j, g_{j'}\}) = m(\{g_j, g_{j'}\}).$$

As it is evident from the formulation of the 2-additive Choquet integral in equation (3), its computation is based:

1 on the fact that the evaluations of a_i on the considered criteria are expressed on the same scale so that the *min* operator is meaningful

2 on the knowledge of the Möbius transformation m of μ.

With respect to the first point, in this paper we applied a development of the AHP presented in Corrente et al. (2016) and briefly recalled in Section 2.1. As to the second point, the SMAA has been applied in this paper and it is recalled in Section 2.3.

2.3 SMAA application

Based on the preference information provided by the experts, to take into account the whole set of vectors of parameters (capacities) compatible with such preferences, we applied the SMAA methodology briefly recalled in the next section.

2.3.1 The SMAA

As introduced in Section 2.2, the application of the Choquet integral implies the knowledge of the Möbius transformation m of the capacity μ. To get m, a direct or an indirect elicitation technique can be used (Jacquet-Lagreze and Siskos, 2001). Using a direct elicitation technique, the DM is able to provide exact values for each of the parameters involved in the model, that is, in our context, a value $m(\{g_j\})$ for each criterion g_j and a value $m(\{g_j, g_{j'}\})$ for each pair of criteria $(g_j, g_{j'})$. With an indirect elicitation technique, the DM is asked to provide preferences in terms of comparison between alternatives ('a is preferred to b' or 'a and b are indifferent'), comparison between criteria with respect to their importance ('g_j is more important than $g_{j'}$' or 'g_j and $g_{j'}$ are equally important') or interaction between criteria ('g_j and $g_{j'}$ are positively interacting' or 'g_j and $g_{j'}$ are negatively interacting') from which an instance of the assumed preference model compatible with such preferences (a Möbius transformation in our context) can be inferred (see Corrente et al., 2019 for a detailed explanation of the way the preferences are translated and, then, used to infer a compatible model).

In general, indirect elicitation techniques are preferred to direct techniques since they involve a less demanding cognitive effort to the DM. Anyway, more than one instance of the assumed preference model compatible with the preferences provided by the DM (a compatible model for brevity) could be inferred and the computation of the Choquet integral with each of them could provide a different recommendation on the problem at hand since a different ranking of the considered alternatives could be obtained. Therefore, instead of using only one compatible model, the SMAA methodology (Lahdelma et al., 1998; Pelissari et al., 2020) provides robust recommendations on the problem at hand by considering simultaneously all the compatible models. The application of SMAA to a ranking problem is based on a sampling of several compatible models and on the computation of the rankings of the alternatives at hand for each of the sampled compatible models. Based on the considered rankings, two indices can be computed:

- The rank acceptability index b_i^s being the frequency with which an alternative a_i reaches the position s in the considered rankings. Of course, the best alternatives will be those presenting high rank acceptability indices for the first rank positions and low rank acceptability indices for the lowest rank positions.
- The pairwise winning index (Leskinen et al., 2006) $p(a_i, a_{i'})$, being the frequency with which alternative a_i is preferred to alternative $a_{i'}$. This can be used in case one is interested in comparing the two alternatives alone, without considering all the other alternatives.

Since in many real-world problems a comprehensive ranking of the alternatives needs to be obtained, to provide a final recommendation on the considered problem, the expected ranking of each alternative a_i can be computed (Kadziński and Michalski, 2016). It is obtained as a weighted sum of the rank acceptability indices described above.

$$ER(a_i) = \sum_{s=1}^{n} s \cdot b_i^s$$

And can be considered as a summary of the alternatives' rankings obtained considering all the sampled compatible models. The alternatives are therefore ordered from the best to the worst with respect to increasing values of $ER(a_i)$.

3 The requalification of an abandoned thermoelectric power plant

Starting from the methodological background reported in Section 2, the decision support procedure we adopted for the case study in exam is articulated in eight steps and sees the involvement of:

1. the authors of the paper acting as the analysts
2. two representatives of ENEL acting as DM
3. 15 teachers of the high-level university program which are the experts having deep knowledge in economic evaluation of projects, design, urban planning, land reclamation, healthcare engineering, energy management, entrepreneurship and innovation of significant social impact.

Table 1 Synthesis of the steps involved in the applied MCDA procedure

Phase	*Activity*	*Theory/approach/knowledge*
1	Structuring the problem and designing the model	Knowledge of the experts and preferences of the DM
2	Definition of the criteria	Knowledge of the experts
3	Rating the alternatives on each considered criterion	Knowledge of the experts
4	Selection of reference evaluations on each criterion	Knowledge and preferences of experts and DM
5	Pairwise comparison of the reference evaluations obtaining normalised values	Parsimonious AHP
6	Prioritisation of all evaluations by interpolation	Parsimonious AHP
7	Interaction between considered criteria	Knowledge and preferences of experts and DM (that could be also based on the literature) and Choquet integral
8	Construction, presentation and discussion of the final alternatives ranking	Choquet integral within SMAA

From Table 1, it is possible to notice that the decision procedure provides qualitative and quantitative phases basing on the knowledge of the experts, the preferences of the DM alternated with the methodologies recalled in Section 2.

3.1 Description of the case study

The thermoelectric power plant of Bari (Italy) has been dismissed in 2013 after a fire that damaged different parts of the plant highlighting problems in terms of security and environmental safety. It is part of the 'Future-e' project (http://corporate.enel.it/en/futur-e), launched and promoted by ENEL as a circular-economy project which aims to reconvert 24 former thermoelectric power plants to create new development opportunities in Italy. At the time this research was carried out, seven plants had already identified a new solution, 11 showed an ongoing decision process to identify new uses (the power plant of Bari is one of those), while for six plants the decision process was not yet started.

Currently, Italy is facing a profound transformation of the energy system. In fact, over the last few years, the consumption of industrial activities has decreased, and the role of renewable energy resources has grown together with the environmental sensitivity. While until few years ago, large power plants provided energy to the entire country, today smaller renewable plants are shaping a new more distributed generation model. Consequently, some traditional thermoelectric power plants have concluded their original use and need to be transformed finding a new life. In this perspective, the ‘Future-e’ project represents the chance to identify new sustainable development stories for different areas basing on the ‘shared value approach’ (Aakhus and Bzdak, 2012; Porter and Kramer, 2019), which consists in a detailed analysis of the context and in the direct involvement of different local stakeholders as public administrations, associations, citizens, business community and energy providers.

The thermoelectric power plant of Bari is characterised by a large size (around 60,000 sqm) and it is in a favourable position in terms of connections and accessibility being placed in an industrial neighbourhood near the city centre and not far from the seaside. Currently, the buildings on the area are in discrete conditions, except for the northern part belonging to the three tanks for fuel oil storage, which shows huge damages related to the fire occurred in 2013 as well as high levels of soil pollution caused by the fuel oils’ spill (Figure 1). Accordingly, the area presents uneven levels of pollution with the consequence that the types of reclamation interventions could be extremely varied.

Figure 1 The ex-thermoelectric power plant of Bari (see online version for colours)

Source: http://corporate.enel.it

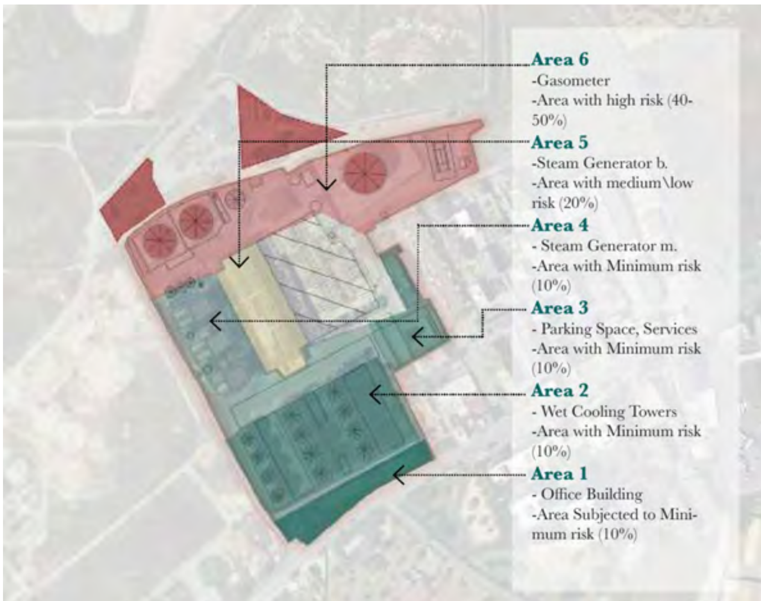
3.2 Structuring the problem and designing the model

The first fundamental step towards the identification of the most interesting alternatives of intervention has been constituted by the definition of a general masterplan for the requalification of the former thermoelectric power plant.

The masterplan as well as the different alternatives of intervention have been developed by the students at the high-level university program putting in place their heterogeneous knowledge in design, architecture, planning for the global urban agenda, management engineering, environmental and land planning engineering as well as petroleum engineering. Both the masterplan and the different alternatives take into consideration the requests of ENEL and see the support of the experts.

The developed masterplan identified three areas according to the level of pollution measured through a probabilistic risk assessment (PRA) (Öberg and Bergback, 2005; Barrio-Parra et al., 2019; Zhang et al., 2021). Hence, the three identified areas have been in turn divided into six sub-areas according to the buildings' typologies and the level of degradation (Figure 2).

Figure 2 PRA and sub-areas (see online version for colours)



In Figure 2, according to the PRA, the green area identifies the spaces in which the level of soil pollution is minimum (10%) being destined to administrative offices, parking, services and wet cooling towers. The yellow area is subject to a medium level of soil pollution (20%). This is in fact the area in which the steam generator was placed. Finally, the red area is characterised by a high level of pollution (40%–50%) being destined to the tanks for fuel oil storage and the coal stock site which are considered as highly pollutant activities.

Basing on the general masterplan defined, it has been necessary to identify possible functions for the former thermoelectric power plants considering the pollutant and buildings' conditions of the six sub areas identified. In this sense, the PRA has been very useful to support the identification of the most appropriate functions in each area able to facilitate the remediation's activities reducing the intervention costs and the environmental risk (Barrio-Parra et al., 2019; Canevaro et al., 2019).

Due to the considerable size of the site and the absence of a precise direction of development of the area by the municipality, the students of the high-level program together with the experts assumed that there were many possible functions and combinations.

To be able to propose functions in line with the characters of the city, the economy and the demographic trends of Bari have been studied and analysed.

First, a strong presence of the so-called blue economy has emerged. In particular, many activities in Bari gravitate around the fishing sector and the production/export of boats (http://unioncamere.gov.it). Second, the cultural and gastronomic sector plays a fundamental role (http://cittametropolitana.ba.it). In fact, specific analyses on tourism trends show that tourists in Bari are constantly growing in number not only for the presence of the sea but also attracted by the historical and cultural value of the artistic heritage and the high value of food and wine products. Finally, an interesting data is related to the strong presence of college students coming to Bari from all over Italy and abroad (https://www.istat.it). Accordingly, the identified functions are the following:

- Housing with reference to student and tourist hosting.
- Services linked to the blue economy (i.e., fish markets, algae farms).
- Artisanal and commercial activities related to production and sale of typical products (i.e. wheat, oil, wine, boats).
- Special functions (i.e., hotels, industries, sports, university campus).
- Green areas.

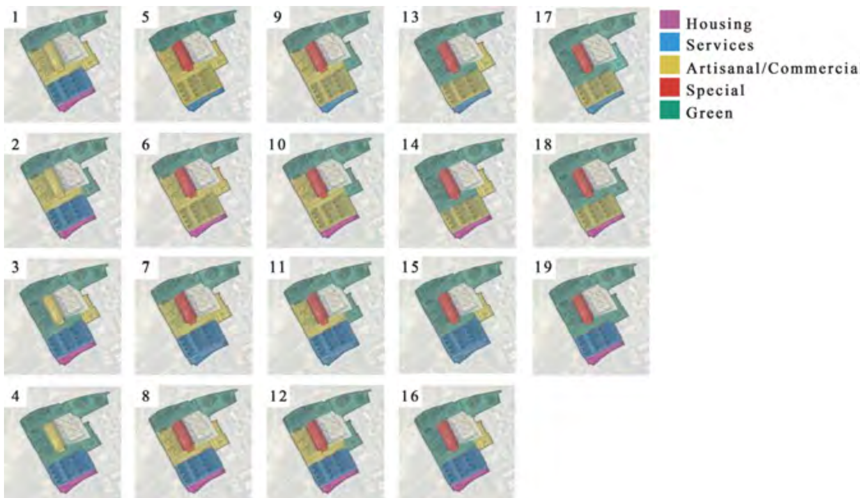
After having identified the general functions, a focus group with the experts has been organised to combine functions considering the intrinsic characters of each sub-area and in the perspective of reducing the costs necessary for soil remediation and the environmental impact of the interventions. During the focus group, these aspects have been emphasised:

- Sub-area 1 has been considered particularly suitable to accommodate functions as residences and services due to positional characters and dimensions. It is in fact a small area facing the road that connects the former thermoelectric power station with the city centre of Bari.
- Sub-area 2 has been considered suitable for commercial activities, industries or services. These activities usually require vast territorial dimension as the one provided by this sub-area.
- Sub-areas 3 and 4 could accommodate small commercial activities, art workshops and garages or could become a big green area. In fact, these sub-areas are not big enough to be suitable for industries or malls but, at the same time, they are not in a strategic position to place residences or services.
- Sub-area 5, due to the medium level of pollution of the soils is not suitable to accommodate residences or services but it could be perfect for functions as small commercial activities or special activities.
- Sub-area 6 presents a high level of pollution of the soil caused by the presence of the former three tanks for fuel oil storage. Has been decided to allocate this space to green areas with modest and discontinuous presence of people so to reduce the remediation's costs.

During the focus group with the experts, it emerged that a functional mix can be considered interesting especially if it shows more than three different functions on the overall area of the former thermoelectric power plant. This is called 'mixité'.

According to this requirement, all the functional mixes not having at least four different functions have been considered not interesting because not able to guarantee a mixture of complementary land use types, which will stimulate investments and increase properties' value. The functional mixes satisfying this requirement turned out to be 19 (Figure 3).

Figure 3 The 19 functional mixes identified (see online version for colours)



The huge number of alternatives makes our application a paradigmatic example of the highly difficult decision-making problems to handle in transformations similar to this one. In this perspective, our application can be considered as a 'stress test' for a multicriteria approach in highly complex decision problems.

3.3 Definition of the decision criteria and rating of the alternatives

After having identified the sample of alternatives of intervention to be compared, it was necessary to define the evaluation criteria able to catch the complexity of the decision problem in exam and to measure the performances of each proposed alternative.

The evaluation criteria have been identified by the analysts basing on the guidelines of the 'Futur-e project'. The first hypothesis of evaluation criteria involved five criteria namely g_1, g_2, g_3, g_5, g_6 (see Table 2). After a discussion with the experts, it emerged the need to consider also g_4 and g_7 so to be able to evaluate the performances of the alternatives in a long-term perspective. These additional criteria have been proposed to the DM and included in the analysis.

The definitive list of evaluation criteria is reported in Table 2 where the column 'scale' indicates the scale of measure of each criterion.

The 19 alternatives and their assessments with respect to the considered decision criteria are shown in Table 3, according to the experts' evaluations.

Table 2 Description of the evaluation criteria

Criterion	*Description*	*Measure*	*Scale*
Diversity (g_1)	It refers to the functional mix characterising every building.	Number of different functions in the buildings	From 1 to 25 functions
Uniqueness (g_2)	It consists in performing the classification of an area basing on the number of existing areas similar to the considered one.	Number of similar areas in the region	From 1 to 3 areas
Community engagement (g_3)	It refers to the level of public participation that each alternative might create, enabling relationships.	Level of public participation that each alternative might create. The considered levels are: 1 inform 2 consult 3 involve 4 collaborate 5 empower	From 1 to 5
Antifragility (g_4)	It considers the possibility of overcoming the intrinsic fragility of a transformation being composed of a multitude of small and medium activities.	Number of independent phases/subprojects in which the alternative can be split into. Each sub area can be considered independent from the others.	From 1 to 5
Induced externalities (g_5)	It considers economic benefits and costs caused by the transformation on the surrounding areas.	Number of positive externalities that the project can activate	From 0 to 8
Minimum threshold of investment (g_6)	It is understood as the minimum investment necessary to make attractive investments and predict realistic scenarios in which the investors can realise which activities and actions are acceptable.	Estimated costs of the adaptive reuse considering also the remediation's costs.	From 10.000.000 to 20.000.000 €
Synergy with other projects (g_7)	It refers to the possible benefits brought by the interdependence and interrelations with other projects.	Number of projects that can interact with the transformation in exam	From 0 to 5

3.4 Selection of the reference evaluation and pairwise comparisons

To compare the alternatives taking into account interaction between criteria we adopted the Choquet integral, which needs that the performances' evaluations of each alternative with respect to the decision criteria be expressed on the same scale. To this aim we considered sensible to use the evaluations provided by AHP (Saaty, 1980). However, application of AHP in its standard formulation to this problem would be problematic for the experts and the DM since it would require $\binom{19}{2} = 171$ pairwise comparisons for each criterion and, therefore, a total of 1,197 pairwise comparisons. As it is evident, providing so huge number of comparisons is prohibitive for whichever DM. For such a reason, we applied the parsimonious AHP proposed by Abastante et al. (2019) and briefly recalled in Section 2.

Table 3 Table of performance

Alternatives	g_1	g_2	g_3	g_4	g_5	g_6	g_7
A_1	10	2	3	5	5	18,251,220 €	3
A_2	15	2	3	4	5	17,731,060 €	3
A_3	20	2	3	4	5	13,755,420 €	3
A_4	25	2	3	5	5	13,235,260 €	3
A_5	10	2	4	5	5	16,008,107 €	3
A_6	7	3	2	5	7	14,539,870 €	3
A_7	10	2	4	4	6	15,997,170 €	2
A_8	7	3	2	5	8	16,509,870 €	4
A_9	10	2	3	4	6	15,346,170 €	2
A_{10}	12	2	2	4	7	13,964,710 €	2
A_{11}	10	2	4	3	6	15,482,010 €	3
A_{12}	12	3	4	5	8	15,999,710 €	5
A_{13}	15	2	3	3	6	11,552,770 €	2
A_{14}	15	2	2	3	7	12,065,470 €	2
A_{15}	18	2	4	3	6	11,552,770 €	2
A_{16}	15	3	3	5	8	12,065,470 €	4
A_{17}	20	2	4	4	6	11,032,610 €	2
A_{18}	17	2	2	3	7	13,082,610 €	2
A_{19}	22	2	4	3	6	11,545,310 €	2

3.4.1 Reference evaluations and pairwise comparison for the considered criteria in the case study

First it was necessary to identify the most appropriate set of reference evaluations in line with the experts' suggestions and to ask them to compare the values shown in Table 4. It should be mentioned that the definition of the reference evaluations could be fixed with a non-'standardised' procedure tailor-made for each criterion of the decision problem (Abastante et al., 2018). In this sense we carried out an interesting discussion with the experts to properly define the reference evaluations of each criterion.

Table 4 Reference evaluations for the considered criteria

g_1	g_2	g_3	g_4	g_5	g_6	g_7
25	3	5	5	8	20,000,000	5
18	2	3	4	6	15,000,000	3
10	1	1	3	3	10,000,000	1
5			2	0		
			1			

As a consequence, the pairwise comparisons asked to the experts were:

- three for the three reference evaluations of the criteria g_2, g_3, g_6 and g_7
- six for the four reference evaluations of the criteria g_1 and g_5
- ten for the five reference evaluations of the criterion g_4.

which gave a total of 40 pairwise comparisons (against 1,197 asked from the classical AHP).

Two examples of pairwise comparisons given by the experts during the aforementioned discussion are reported in Table 5.

Table 5 Pairwise comparison matrices for two of the considered criteria

	g_1 (Diversity) CR = 0.02				*g_5 (Induced externalities) CR = 0.01*			
	25	*18*	*10*	*5*		*8*	*6*	*3*	*0*
25	1	1/7	1/3	1/3	8	1	2	3	9
18	7	1	3	5	6	1/2	1	3	7
10	3	1/3	1	1	3	1/3	1/3	1	3
5	3	1/5	1	1	0	1/9	1/7	1/3	1

3.4.2 Prioritisation of all evaluations by interpolation

Considering the normalised evaluations obtained by the application of AHP to the reference performances (Table 6) and interpolating them as described in Section 2, we are able to obtain the normalised evaluations of the functional mixes corresponding to the considered structured plans with respect to all criteria reported in Table 7.

Table 6 Reference evaluations for considered criteria and normalised values obtained by AHP

g_1	*Normalised*	*g_2*	*Normalised*	*g_3*	*Normalised*	*g_4*	*Normalised*
25	0.1099	3	0.0837	5	1	5	1
18	1	2	0.1894	3	0.4421	4	0.8563
10	0.3064	1	1	1	0.0837	3	0.3131
5	0.2736	-	-	-	-	2	0.0767
-	-	-	-	-	-	1	0.0767

g_5	*Normalised*	*g_6*	*Normalised*	*g_7*	*Normalised*
8	1	20.000.000	0..0837	5	1
6	0.6639	15.000.000	0..4421	3	0.9196
3	0.2786	10.000.000	1	1	0.1208
0	0.0981	-	-	-	-

For example, to obtain the normalised value of the functional mix A_1 with respect to the criterion g_5, we observed that its evaluation (5) is in the interval of the reference evaluations 3 and 6 for g_5. Since the normalised evaluations of the two reference evaluations obtained by AHP are respectively 0.2786 and 0.6639, applying equation (1) we get the normalised evaluation of g_5 for the functional mix A_1 as follows:

$$u(5) = 0.2786 + \frac{0.2786 - 0.6639}{3-6}(5-3) = 0.5355.$$

Table 7 Alternatives with normalised evaluations on each criterion

Alternatives	g_1	g_2	g_3	g_4	g_5	g_6	g_7
A_1	0.3065	0.1894	0.4422	1	0.5355	0.2091	0.9197
A_2	0.7399	0.1894	0.4422	0.8564	0.5355	0.2464	0.9197
A_3	0.7457	0.1894	0.4422	0.8564	0.5355	0.5810	0.9197
A_4	0.1100	0.1894	0.4422	1	0.5355	0.6390	0.9197
A_5	0.3065	0.1894	0.7211	1	0.5355	0.3700	0.9197
A_6	0.2868	0.0837	0.2630	1	0.8320	0.4935	0.9197
A_7	0.3065	0.1894	0.7211	0.8564	0.6639	0.3707	0.5203
A_8	0.2868	0.0837	0.2630	1	1	0.3339	0.9598
A_9	0.3065	0.1894	0.4422	0.8564	0.6639	0.4173	0.5203
A_{10}	0.4798	0.1894	0.2630	0.8564	0.8320	0.5577	0.5203
A_{11}	0.3065	0.1894	0.7211	0.3132	0.6639	0.4076	0.9197
A_{12}	0.4798	0.0837	0.7211	1	1	0.3705	1
A_{13}	0.7399	0.1894	0.4422	0.3132	0.6639	0.8268	0.5203
A_{14}	0.7399	0.1894	0.2630	0.3132	0.8320	0.7696	0.5203
A_{15}	1	0.1894	0.7211	0.3132	0.6639	0.8268	0.5203
A_{16}	0.7399	0.0837	0.4422	1	1	0.7696	0.9598
A_{17}	0.7457	0.1894	0.7211	0.8564	0.6639	0.8848	0.5203
A_{18}	0.9133	0.1894	0.2630	0.3132	0.8320	0.6561	0.5203
A_{19}	0.4914	0.1894	0.7211	0.3132	0.6639	0.8276	0.5203

3.5 Interaction between the considered criteria in the case study

In line with the methodology described in Section 2, the experts were able to provide the following preference information in terms of interaction between criteria:

1. Uniqueness (g_2) and minimum threshold of investment (g_6) are positively interacting: the experts affirmed that this interaction reflects the ability of a unique project of favouring the attraction of huge investments being potentially characterised by a high market value.
2. Synergy with other projects (g_7) and uniqueness (g_2) are positively interacting: according to the experts' suggestions, designing a project in synergy with existing projects on the territory in exam can underline which are the missing points required to enhance the potential of the area. This will allow to create a unique project.
3. Minimum threshold of investment (g_6) and induced externalities (g_5) are positively interacting: the experts affirmed that the more the project can activate positive externalities on the territory, the more potential investors are attracted. The idea is that the investors aim at increasing their reputation in the territorial context.

4 Diversity (g_1) and uniqueness (g_2) are positively interacting: according to the experts' logic, pursuing the realisation of a unique project will promote the diversity in terms of functional mix.

5 Uniqueness (g_2) and (g_5) are positively interacting: in line with the previous induced externalities interactions, the experts affirmed that a unique project could favour the positive externalities on the territory in exam.

Together with the interaction between criteria, the experts were also able to provide an order of the decision criteria in terms of their importance. After a debate, they decided to provide the importance ranking as follows: $g_4 \succ g_6 \succ g_5 \succ g_3 \succ g_2 \succ g_7 \succ g_1$, where, in this context, the symbol $\succ$ must be read as 'is more important than'.

3.5.1 SMAA application to the case study

We applied the SMAA method by sampling 100,000 capacities compatible with the information related to importance and interaction of criteria provided by the experts. For each one of the capacities in the sample, we computed the Choquet integral of the 19 alternatives.

Looking at Table 8, it is possible to notice that each alternative of intervention can fill different positions depending on the built common scale and on the sampled capacity compatible with the preferences expressed by the experts and the DM. It is interesting to stress out that the first position can be filled in by A_{12}, A_{16} and A_{17} even if with a different probability. In details, one can see that A_{16} can fill the first position more frequently (81.81%) followed by A_{17} (10.51%) and A_{12} (7.69%). At the same time, A_{16} can reach only the first four positions, A_{12} the first 6 and A_{17} the first 8 (even if the positions from the 5th to the 8th are reached with a very small probability) showing, therefore, quite stable results.

As far as it concerns the last position, the situation seems to be clearer since A_{11} is the worst among the 19 different alternatives of intervention with a quite high frequency (78.30%). Only A_{18} is the other alternative presenting a relevant probability to take the last ranking position that is 20.38%. However, A_{11} is worse than it.

To compare pairwise the first three alternatives of intervention, that is A_{12}, A_{16} and A_{17}, we report their pairwise winning indices shown in Table 9.

Looking at these values, one has the confirmation that A_{12} is the best among the considered alternatives of intervention since it is preferred to the other two alternatives with a frequency at least equal to the 88.58%. The second best is A_{12} being preferred to A_{17} in 63.85% of the cases, while A_{17} can be considered the third functional mix.

As explained in Section 2, to get a final complete ranking of the 19 functional mixes summarising the results of the SMAA application, we computed the expected ranking shown in Table 10. Once again, we have the confirmation that A_{12}, A_{16} and A_{17} fill in the first three ranking positions in this order, while A_{18} and A_{11} are the last ones in the considered ranking.

The provided information is robust since it considers a plurality of models compatible with the preferences provided by the experts instead of only one. Even if a unique final ranking is provided, this is the summary of all the different rankings that have been obtained varying the capacities compatible with the provided preferences.

Table 8 Rank acceptability indices of the considered functional mixes expressed in percentage

	#1	*#2*	*#3*	*#4*	*#5*	*#6*	*#7*	*#8*	*#9*	*#10*	*#11*	*#12*	*#13*	*#14*	*#15*	*#16*	*#17*	*#18*	*#19*
A_1	0	0	0	0	0.01	0.14	1.86	5.59	13.49	14.60	9.71	11.50	12.41	10.26	5.97	5.62	6.82	2.02	0
A_2	0	0	0	0	0.52	7.60	4.06	4.11	6.70	8.21	10.75	12.44	12.96	8.12	9.10	7.32	5.34	2.68	0.10
A_3	0	0	0.43	17.76	21.07	19.74	14.42	14.48	9.96	1.86	0.29	0	0	0	0	0	0	0	0
A_4	0	0.01	2.54	8.77	17.85	21.45	23.88	11.82	5.77	3.85	2.55	1.09	0.41	0	0	0	0	0	0
A_5	0	0.64	7.97	45.78	24.19	11.19	6.37	1.87	1.99	0.01	0	0	0	0	0	0	0	0	0
A_6	0	0	0.25	4.32	9.35	13.49	13.12	16.61	13.28	10.90	6.43	5.68	2.35	1.33	1.69	0.49	0.71	0	0
A_7	0	0	0	0	3.64	2.90	6.01	10.93	10.02	18.75	18.86	14.78	10.27	2.90	0.82	0.11	0	0	0
A_8	0	0	2.73	8.57	10.23	8.96	8.90	10.24	8.75	9.70	9.72	6.23	4.63	2.77	2.15	1.31	1.71	2.72	0.69
A_9	0	0	0	0	0	0	0	0	0	0.11	1.45	4.18	11.08	24.16	27.74	10.04	8.64	12.16	0.45
A_{10}	0	0	0	0.09	0.61	1.00	4.86	5.49	10.20	10.61	11.38	14.73	13.54	12.20	6.13	5.15	3.22	0.78	0.03
A_{11}	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.67	0.85	4.30	7.00	8.87	78.30
A_{12}	7.69	58.30	31.19	2.29	0.43	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0
A_{13}	0	0	0	0	0	0	0	0.05	1.11	0.82	3.02	4.00	5.07	9.16	14.39	47.54	14.78	0.07	0
A_{14}	0	0	0	0	0	0.33	0.51	0.78	1.84	3.07	1.94	2.64	4.05	4.81	9.60	12.14	42.74	15.50	0.06
A_{15}	0	0	0.53	4.30	10.10	12.28	14.66	11.70	11.51	9.70	9.37	6.21	6.05	3.60	0	0	0	0	0
A_{16}	81.81	14.59	2.94	0.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A_{17}	10.51	26.45	51.42	7.45	2.03	0.81	1.25	0.08	0	0	0	0	0	0	0	0	0	0	0
A_{18}	0	0	0	0	0	0	0	0	0.04	0.75	0.97	1.82	1.45	3.34	2.55	4.88	8.65	55.18	20.38
A_{19}	0	0	0	0	0	0.01	0.11	6.24	5.34	7.09	13.57	14.70	15.73	16.69	19.01	1.11	0.40	0.02	0

Table 9 Pairwise winning indices for the three functional mixes presenting the highest frequencies in correspondence of the first positions

	A_{12}	A_{16}	A_{17}
A_{12}	0	9.85	63.85
A_{16}	90.15	0	88.58
A_{17}	36.15	11.42	0

Table 10 Expected ranking of the considered functional mixes

Alternative	*Value*	*Alternative*	*Value*
A_{16}	1.2149	A_{2}	11.7800
A_{12}	2.2767	A_{10}	11.8581
A_{17}	2.7549	A_{1}	12.0620
A_{5}	4.7371	A_{19}	12.4737
A_{3}	6.1786	A_{9}	15.0617
A_{4}	6.7381	A_{13}	15.2660
A_{6}	8.2818	A_{14}	15.7629
A_{15}	8.4356	A_{18}	17.4810
A_{8}	8.8215	A_{11}	18.5790
A_{7}	10.2364		

4 Discussion

The preferred alternative A_{16} provides the following functions: housing, services, artisanal/commercial, special and green areas displaced in areas 4 and 6 (Figure 3) in the perspective of creating a big park.

In terms of functional mixes, this alternative perfectly reflects the demands of the experts because it provides five different functions in the same area. Moreover, this alternative is the one that best meets the requirements of the experts in terms of considered criteria. In fact, they expressed the following ranking of criteria in terms of their importance: g_4 (antifragility) $\succ$ g_6 (minimum threshold of investment) $\succ$ g_5 (induced externalities) $\succ$ g_3 (community engagement) $\succ$ g_2 (uniqueness) $\succ$ g_7 (synergy with other projects) $\succ$ g_1 (diversity). With this respect, alternative A_{16} shows a very high performance in g_4 being composed of a multitude of different functions and small/medium activities. It is also excellent on g_6, understood as the minimum investment necessary to make attractive investments and predict realistic scenarios in which the investors can realise which activities and actions are acceptable. In addition, the land reclamation costs are reduced thanks to the design of a large green area, which requires capping and not complete soil replacement (Reis et al., 2019). Finally, it is highly performing on g_5 being able to generate economic benefits on the surrounding areas thanks to the perfect functional mix.

The second preferred alternative A_{12} looks very much like the first as a functional mix foreseeing the following functions: housing, services, artisanal/commercial, special and green areas. Despite both A_{16} and A_{12} provide five heterogenous functions, there are two main differences:

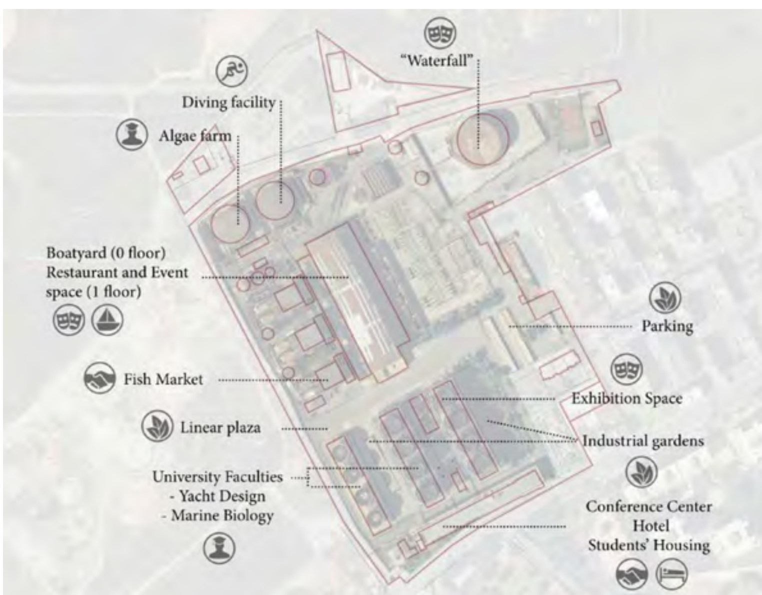
1 A_{12} does not provide for a big park since the green areas are not adjacent being displaced in areas 3 and 6

2 A_{12} shows a higher area in terms of artisanal/commercial function.

This is reflected in the performance of the criteria. In fact, according to criterion g_6, A_{12} very bad performing probably due to high costs needed to start the transformation.

The third preferred alternative A_{17} provides the following functions: services, artisanal/commercial, special and green areas displaced in areas 3, 4 and 6. Compared to A_{16} and A_{12}, alternative A_{17} is aimed at creating a sort of green lung for the city. In fact, here the functional mix is composed by four functions, sacrificing the housing function in favour of a greater green area. This is inevitably reflected by the performance of the criteria as defined by the experts. According to g_4, which is considered as the most important criterion, alternative A_{17} performs not so good as A_{16} and A_{12}. Moreover, the presence of a green lung affects the possibility of synergy with other projects and consequently reduces the performance of the alternative on g_7.

Figure 4 Design declination of alternative A_{12} (see online version for colours)



After having discussed the final ranking with the DM, he decided to investigate alternative A_{12} instead of alternative A_{16}. As often happens in decision-making processes of a territorial nature, the DM has opted for the alternative capable of producing greater profitability. This is in line with the objectives of MCDA procedures that aim to supply a recommendation based on elements of reasoning leaving the DM the ultimate responsibility for the definitive decision (see e.g., Roy, 1993). Moreover, observe in Table 9 that there was anyway a probability of 9.85% that alternative A_{12} could be preferred to alternative A_{16}, so we can conclude that the preferences represented by the compatible capacities compatible constituting the 9.85% probability in favour of A_{12} over A_{16} prevailed and informed the final decision.

The students at the high-level university program have been called to provide a more detailed project for the area in exam considering the functional mix of alternative A_{12} (Figure 4).

The project incorporates the strategic lines in terms of functions that have emerged from economic and demographic analysis (see Section 3.1). In area 1 a conference centre together with the students' housing are provided so as to help to solve the problem of the growing number of students in the city. In area 2, destined to services, the university faculties are placed while in area 3 a park with parking has been planned. Areas 4 and 5 have been destined to artisanal and commercial activities linked to the blue economy (fish market, boatyard, restaurant). Finally in area 6 a park together with amusement activities is designed.

5 Conclusions

Large Brownfield sites, often considered unusable and without market value at the time they were abandoned, are now the subject of increasing attention due to their size, location and a new culture of adaptive use of existing real estate. However, these vast areas have been frequently approached as desolate empty lots to be simply filled with new functions, without considering the spatial potential of the pre-existing structures and the cultural heritage of this industrial archaeology. The chimneys, the tanks for fuel oil storage, the gasometers, represent for the industrial city a landmark full of meaning in the same way as the cathedral, the bell tower, the castle, or the market square in the traditional historical city (Romano, 1993). Thus, it is possible to recognise an economic value and a cultural value also in an abandoned thermoelectric power plant: if the former can be quite evident with respect to the construction costs, the latter is an expression of the interaction over time between people and places. In addition to these value aspects, several constraints and expectation must be considered, from the environmental to the social ones.

To help the DM to handle these very varied information and values, this paper illustrates a robust multi-criteria framework useful for the preliminary analysis of vast Brownfield sites and above all for their redesign and the assessment of the quality of the projects and constructions proposed for their redevelopment.

As the case study of the Bari power station shows, the vast size of this type of area can result in a very large number of transformation alternatives to be compared, based on several criteria not expressed on the same unit scale and not necessarily independent, demanding at the same time an acceptable level of cognitive effort to the DM. The issue of limiting the cognitive effort arises from two needs: not only, of course, to ensure that the DM is able to provide all the answers required, but also to allow a better understanding of the different steps of the methodological framework, to ensure its traceability and thus greater legitimacy. The combination of different methods proposed here is intended to maintain the scientific soundness and at the same time offer a viable path to those who must support DMs in the challenges that the territory presents today, related to its environmental fallout as well as economic and social ambition. Finally, we emphasise that the result, i.e., the expected ranking of alternatives compatible with the provided preferences, is easily readable and communicable in any decision-making arena.

As further directions of research, we plan to perform some experiments to improve the proposed multicriteria decision support methodology also including a GIS tool, to make it even more effective regarding decision-making problems related to planning.

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