How to implement a participatory decision support for contaminated brownfield? A case study from France

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Abstract

Currently, participatory evaluation processes using multicriteria decision aids are barely used in the context of contaminated sites, even though they are a powerful tool for supporting land-use decision-making. The aim of this paper is to show how to apply such a participatory evaluation process (mixed methods) to the redevelopment of a contaminated brownfield site in France. Following the Model for the Operationalization of Democratic Evaluation (MODE), we designed a participatory process that enabled stakeholder empowerment to implement participatory multicriteria evaluations. We show that the (Elimination and Choice Expressing Reality) ELECTRE I method can be used to select consensus-based brownfield redevelopment projects and that such a participatory process can be implemented to ensure that feasible, coherent, and transparent choices are made for other brownfield redevelopment processes.

Keywords: Brownfield; ELECTRE; Group decision; Multicriteria Decision Aid (MCDA); Participatory evaluation.

1. Introduction

As free developable land is a scarce resource in urban areas, brownfields are becoming important potentials for sustainable development (Dorsey 2003). Brownfield is any land which has previously been used or developed and is not currently fully in use, although it may be partially occupied or utilized (Alker et al. 2000). Due to being previously used for industrial activities, brownfields are often contaminated sites (Oliver et al. 2005; Van Liedekerke et al. 2014). This potential contamination raises juridical problems regarding environmental liability (Alberini et al. 2005) as well as financial problems due to uncertainties regarding the sources

and the effective level of contamination (Bartke 2011; Filip and Cecean 2012; Wu et al. 2017). For these reasons, a wide range of laws has been instituted to promote brownfield redevelopment. In France, the 2014 Access to Housing and Urban Renovation Law (ALUR) is the most recent legislative attempt to remove financial and legal obstacles to the reuse of brownfields.

However, brownfield redevelopment remains a major policy challenge (Leger, Balch, and Essex 2016). Indeed, brownfield redevelopment policies need to take into account multiple criteria derived from environmental, social and economic objectives (Kiker et al. 2005). These criteria may be opposing and sometimes incommensurate, which is very common when considering aesthetic or historic criteria for instance. Furthermore, stakeholder expectations have to be taken into account to design effective policies (Cappuyns and Kessen 2014) and to reduce the risk of conflicts (Duijn et al. 2016; Gallagher and Jackson 2008). The European legal framework through, for instance, the Aarhus convention in 2002 and the European directive of 28th January 2003 (2003/35/CE) on access to environmental information, stipulates effective public participation to environmental decision-making processes. Within the French legal framework, this principle is also instituted: Voynet law (1999); Grenelle 1 (2007); Grenelle 2 (2010). These legal requirements correspond to an increasing desire expressed by citizens over recent years to participate in the brownfield redevelopment process (Res Republica, Institut de la concertation et de la participation citoyenne, and Harris Interactive 2017). However, involving stakeholders in environmental decision-making processes is a daunting task because they may have different and potentially conflicting interests (Duijn et al. 2016; Cappuyns and Kessen 2014). Numerous guidelines for implementing participatory processes exist (Santé Canada, Secrétariat de la consultation ministérielle, and Direction générale des communications et de la consultation 2000; Hazebrouck, Baumont, and Legout 2008; Government of Western Australia 2014), though they are rarely used. Ideally, they need to be formally incorporated into a framework readily applicable to contaminated site redevelopment projects (Linkov et al. 2005; Arvai, Gregory, and McDaniels 2001). Currently, they do not enable participants to comprehend key facets related to site constraints and redevelopment processes. Furthermore, they often do not take stakeholder values into consideration and are mainly focused on economic costs (Arvai, Gregory, and McDaniels 2001; Hara 2003; US EPA - Environmental Protection Agency 2005).

The instruments needed, how they should be applied over a project's lifetime, and whether the way they are applied lead to the desired results regarding contaminated brownfield management are issues that need to be resolved where brownfield redevelopment is concerned (ADEME 2011; Alexander 2015). Based on these requirements, this paper aims to show how such a participatory evaluation process can be applied to a real-life decision problem: the redevelopment of a contaminated brownfield site in France. Using the Model for the Operationalization of Democratic Evaluation (MODE) developed by Floc'hlay and Plottu (1998), we have designed a participatory process that fosters stakeholder empowerment to implement participatory multicriteria evaluations. MODE consists of three main components: empowerment; participatory evaluation and multicriteria evaluation (Floc'Hlay and Plottu 1998). These phases enable the widest possible participation of stakeholders in an evaluation process, and facilitate decision-making by identifying and thwarting any risk of conflict. MODE has been used in the evaluation of educational science (Wood, Lawrenz, and Haroldson 2009) and as a basis for "democratic planning and evaluation" in social geography and development (De Marchi 2005). It appears in Sage Benchmarks in the Social Research Methods series (Stern 2005). Some parts of the model have been applied to landscape management (E. Plottu and Plottu 2007; E. Plottu and Plottu 2012), but never to redevelopment processes applied to contaminated brownfields.

This paper is organized as follows. Section 2 explains the existing gap in the literature on operating tools and participatory processes in the context of contaminated site management. Section 3 focuses on the case study and the contextual elements of the French contaminated brownfield to which our methodological framework was applied. Section 4 deals with the implementation phase and demonstrates how MODE can be applied. It also shows that outranking multicriteria methods, and especially the ELECTRE (Elimination and Choice Expressing Reality) I method, can be adequately designed and applied to obtain effective and doable solutions in selecting a brownfield redevelopment project. We discuss our results in the light of existing literature in section 5. Section 6 is the conclusion and gives some suggestions for future research.

2. Participatory process using multicriteria decision-making methods for brownfield sites

This section presents a quick overview of multicriteria decision-making (MCDM) methods and especially the ELECTRE methods. It explains reasons why the ELECTRE I method was selected in our case study (1). It ends by presenting prerequisites for implementing an integrated approach towards the complex management of contaminated brownfield sites based on MODE (2).

1. A quick overview of MCDM and the ELECTRE I method

MCDM groups well-suited methods together to address complex environmental and urban planning issues requiring socio-economic, ecological, cultural, political and technical factors to be taken into account simultaneously (Cinelli, Coles, and Kirwan 2014). From a mathematical viewpoint, MCDM methods are defined by a set of alternatives ($A_i;\ \forall i = 1, \dots, n$) ; a set of criteria ($C_j;\ \forall j = 1, \dots, m$); and a set of weights ($W_j\ ;\ \forall j = 1, \dots m$) that provides information on the relative importance of criteria. Whatever the MCDM methods used, they all serve to organize data into a performance table containing the evaluation for each alternative A_i for a given criterion C_j. They differ however in the way they synthetize this information using optimization algorithms or a dominance approach.

Our approach is based on the European School of multicriteria decision analysis that emerged in the mid-1960s, with the ELECTRE methods (Bernard Roy and Vanderpooten 1996; Zopounidis 1997). These methods aim to compare alternatives pairwise for each criterion expressed in different units, without requiring unit normalization or monetarization. This is of practical interest when data are difficult to quantify or monetarize, as is the case with subjective criteria (Cinelli, Coles, and Kirwan 2014). Hence, it avoids the many limits of a mono-criterion approach, such as cost-benefit analysis. Besides, these methods are also able to deal with potentially conflictual criteria or objectives. Thus, they create a structure to help with decision-making (Bouyssou et al. 2000; J. Figueira, Greco, and Ehrgott 2004; Vincke 1998). From a theoretical and methodological point of view, our approach differs from the multi-attribute utility theory (MAUT). This theory is based on a performance aggregation approach requiring the identification of utility functions and weights for each attribute that can then be assembled in a unique synthesizing criterion (Keeney and Raiffa 1976; Dyer 2005).

Among the many MCDM methods available, we privileged outranking approaches. An outranking relation is a binary relation S defined using the set of alternatives A_i. This relation is associated with preference (strict or not), indifference, or incomparability. An outranking relation $A_1 \mathrm{S} A_2$ is valid if a sufficient majority of criteria C_j is consistent with it. In other words,

alternative A_1 outranks alternative A_2 if the performance of A_1 on a given criterion $C_j; \forall j = 1, \dots, m$ is at least as good (superior or equal) as that obtained for A_2 for the same given criterion. The construction of this outranking relation is based on two major concepts: the concordance index and the discordance index. Their construction varies according to the ELECTRE method used.

The choice of ELECTRE method depends on the problematic: choice ($P.\alpha$); sorting ($P.\beta$); or ranking ($P.\gamma$). A choice problematic aims to select the best alternative from all feasible alternatives. It is composed of ELECTRE I, IS and IV methods. A sorting problematic aims to assign actions into predefined classes, according to norms for instance. This is the objective of all the ELECTRE TRI methods. A ranking problematic aims to rank different alternatives in a decreasing order of preference. It includes ELECTRE II, III, Iv (J. R. Figueira et al. 2013; B Roy and Bouyssou 1993; Bernard Roy 1985).

The ELECTRE I method was judged to be thoroughly appropriate for three main reasons. Firstly, it aims to select the right alternatives from a given small set of alternatives, as is the case with a choice problematic concerning different brownfield redevelopment projects (Bernard Roy and Słowiński 2013). Secondly, it is a simple and transparent method that can easily be implemented in the field (J. R. Figueira et al. 2013). Indeed, we can integrate information given by respondents regarding criteria and their weighting, i.e., their relative importance. Thirdly, it could be integrated into a larger methodology (Govindan and Jepsen 2016), such as participatory processes. Hence, by combining multicriteria approaches with appropriate participatory techniques, an integrated approach to the complex management of contaminated brownfield could be achieved.

In the case of the ELECTRE I method, concordance indexes are established by adding the weights (w_j) of the criteria verifying the outranking relation to the total sum of the weights. They vary between 0 and 1. An index is equal to 0 if there is no criterion for which the considered A_i alternative outperforms another alternative. However, it is equal to 1 when the considered A_i alternative outperforms another alternative for all its criteria. Discordance indexes correspond to the maximal difference between the performance of alternatives regarding all alternatives and the criterion selected. These indexes have to be computed for every pair of alternatives given concordance and discordance levels. Once the smallest possible set of alternatives has been selected, it may be helpful to build a decision graph based on the outranking relations. In this case, A_1 outranks A_2 if there is an arrow between the two alternatives. They are indifferent if the arrow is reversed between the two alternatives. Lastly, they are incomparable if there is no arrow. Table 1 summarizes the main outranking relations and the graphical representations we later apply to our case study.

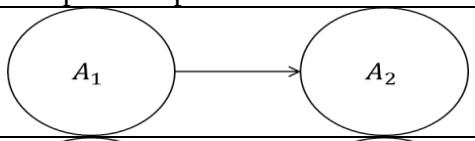
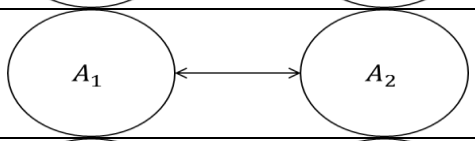
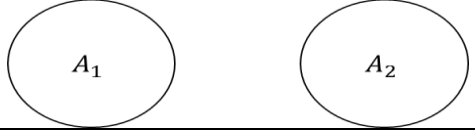
Outranking relations	Graphical representation associated
$A_1 \succ A_2$; A_1 is preferred to A_2	
$A_1 = A_2$; A_1 is indifferent to A_2	
$A_1 \neq A_2$ i ; A_1 s incomparable to A_2	

Table 1 : Outranking framework and its graphical representations

2. A brief literature review of MCDM with a focus on brownfields

MCDM methods are widely used in ecological economics (Huang, Keisler, and Linkov 2011; Kiker et al. 2005). Regarding brownfields, there has been an increasing amount of literature over recent years on prioritization methodologies and tools for contaminated sites using MCDM. These methods aim to identify which contaminated sites should be redeveloped in priority to plan strategies for fund allocation (Cheng et al. 2011; Chrysochoou et al. 2012; Pizzol et al. 2016; Bartke et al. 2016). They are also used to assess the sustainability of contaminated land regeneration according to the three pillars of sustainability (Laprise, Lufkin, and Rey 2015; Morio, Schädler, and Finkel 2013; Riera Pérez and Rey 2013; Rosén et al. 2015; Burinskienė et al. 2017). Furthermore, MCDM methods are also applied to select the most suitable remediation techniques given a site's constraints (Janikowski, Kucharski, and Sas-Nowosielska 2000; Linkov et al. 2005; Onwubuya et al. 2009).

To the best of our knowledge only two studies present a real-world application of multicriteria approaches, namely in the case of quarry sites and using a panel of experts (Mateus, Bana e Costa, and Matos 2016; Morio, Schädler, and Finkel 2013).

Morio et al. (2013) proposed a framework to support decision-making for brownfield redevelopment projects by identifying cadastral-based mixed land-use options that were optimal from an economic perspective (costs) and suitable with respect to sustainable development (environmental and social criteria). Their approach was context-specific and enhanced the transparency of the decision-making process, and objective-oriented regarding the three pillars of sustainable development. However, optimal land-use scenarios were not determined using a participatory approach.

Mateus et al. (2016) conducted at distance a participatory process supported by numerous MACBETH (Measuring Attractiveness by a Category Based Evaluation Technique) approaches to evaluate and select sustainable redevelopment projects for the São Domingos mine in Portugal. Ten experts were chosen according to their spatial scale (from local to national) and their specific knowledge of the site regarding environmental, social or economic issues. They conducted a one-day decision conference with these ten experts to discuss key concerns regarding the São Domingos mine. Once concerns and dimensions regarding the three pillars of sustainable development were defined, each participant was asked to weight the different dimensions using an online MACBETH voting procedure.

All these applications were limited to evaluations from experts and did not include all relevant stakeholders, such as lay citizens, who may have had specific knowledge regarding the brownfield site to be redeveloped. The literature is therefore quite sparse regarding participatory processes using MCDM methods where contaminated site management, and especially brownfield sites, are concerned (Bartke and Schwarze 2015; Thomas 2003). As a result of this, a recent meta-evaluation of assessment and monitoring tools for brownfield sites emphasized the need for participatory frameworks (Pediaditi, Doick, and Moffat 2010) proposing a broader and integrated portfolio of decision techniques that include all relevant stakeholders (Dias-Sardinha et al. 2012; Pollard et al. 2004).

3. Case study: background to the French contaminated brownfield site studied

In this section, we present the case study and its contextual elements, including soil and water contamination (1). Then, we turn to the stakeholders identified as relevant and taken into account in the case of our participatory framework (2, 3).

1. Case study

The decision problem analysed concerned the evaluation and the selection of alternative options for the redevelopment of a contaminated brownfield site located in the neighbourhood of "Alleud", in the municipality of "La Possonnière" ("Maine-et-Loire" department) in the north-west of France (2 416 inhabitants). This site covered a total surface area of 2 hectares (around 2/3 is built-on). Houses and the railway to the north surrounded it as shown in Figure 1.

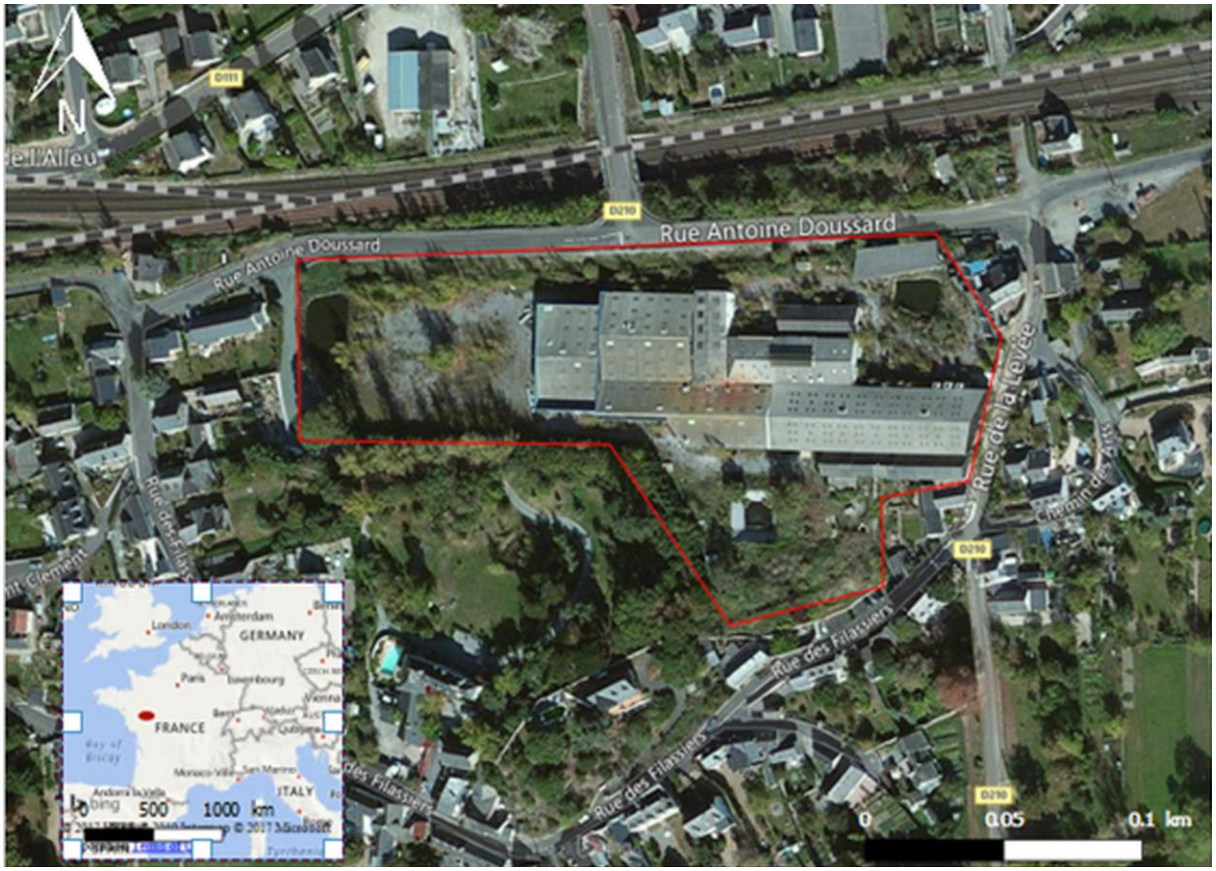


Figure 1: The contaminated brownfield site investigated

During the First World War and until 1926, this uncultivated land was transformed into a smelting plant. Then, between the 1930s and the 1950s, there was a dairy on a part of the site. From the 1960s and until 2004, there were numerous surface treatment activities. Due to these previous activities, the site was listed in "Basol", the French database on contaminated sites for soil contamination. Indeed, simplified and expanded risk assessments showed a soil contaminated with heavy metal and groundwater contaminated with halogenated solvents: trichloroethane (up to 29000 µg/l,) and trichloroethylene (up to 1036 µg/l) (ADEME 2015). Consequently, a prefectural decree issued in 2004 prohibited the consumption of water from

wells. Moreover, as the last manager was declared bankrupt in 2004, it was an orphan site and characterized by uncontrolled vegetation growth.

As of 2014, the French Environment and Energy Management Agency (ADEME) had conducted biannual groundwater monitoring (ADEME 2015). Besides, a Public Utility Easement was underway to guarantee the safety of residents and future owners for any future usage. This residual contamination was viewed as a constraint because contaminated brownfield redevelopment is dependent on the sensitivity of future uses (Ministère de l'Environnement, de l'Énergie et de la Mer 2017). More specifically, the local urban masterplan restricted any future industrial uses.

This brownfield site was ideal for implementing our participatory framework in many ways. Firstly, as the last manager had been declared bankrupt in 2004, tensions had appeased over time and a participatory process could be envisaged. Secondly, as an orphan and abandoned site, decontamination costs were to be covered by ADEME. Additionally, there were no other brownfield redevelopment projects in the making at the time of our study. All this meant that stakeholder involvement was strongly supported by both the municipal council and the inhabitants, who wanted to find a solution to redevelop this area for the future.

2. Stakeholder identification

Historical and institutional analyses were the first step in understanding the cultural context in which the problem was embedded. These analyses were performed through studying the local history and press releases about the brownfield site, using data from Europresse and from the municipality website.

These data were also completed by an in-depth interview with the mayor. This in-depth interview lasted approximately one hour. Data about the history of the site, and in particular past activities and the level of contamination of the site, were collected. This allowed us to understand site constraints and difficulties faced by the municipal council regarding possible redevelopment projects. Furthermore, this in-depth interview yielded preliminary insights on the different groups of stakeholders and the relationships between them. We defined them as any individual or group who can affect or is affected by the brownfield redevelopment project (English et al. 1993). Four broad categories of stakeholders were identified *a priori* as relevant: former employees; the general population; members of a residents' association called ARUA ("Association des Riverains de l'Usine de l'Alleud" - association of the residents of the factory of the Alleud neighbourhood); and elected representatives.

ARUA is a local association dedicated to preserving the environment and daily quality of life of individuals living near the contaminated brownfield site. This association was created in 2000 and was composed of around ten members at the time of the study.

Former employees were individuals having worked at the site. Hence, they knew the site, its infrastructures and history. They were included to analyse the potential heritage value that could be attributed to the brownfield and that needed to be preserved and restored as part of the final urban planning project.

The general population comprised individuals who were living in the municipality and were neither members of the ARUA, nor former employees.

The elected representative category was composed of three individuals: the mayor of the municipality of "La Possonnière" and two town councillors.

All these categories of stakeholders were relevant considering either their potential role in the decision-making process, or their knowledge and interests regarding the brownfield site, as they were all living in the municipality impacted by the brownfield site.

3. Presentation of an evaluative participatory framework using mixed methods

Involving the public in decision-making requires three elements according to MODE (Floc'Hlay and Plottu 1998; B. Plottu and Plottu 2010): empowerment, participatory evaluation and multicriteria evaluation.

Empowerment is the first step and a prerequisite to ensuring a balanced dialogue between the groups of participants (E. Plottu and Plottu 2012). Indeed, this phase relies on the forming and expression of different points of view, especially for the weakest and generally unvoiced and disorganized interest groups, with no common position to defend, such as young people, the unemployed and more broadly speaking, lay people. As a result, it requires a certain given time to inform, mobilize, and guide stakeholders during the evaluative process (Floc'Hlay and Plottu 1998). The objective of this first step is also to raise stakeholders' awareness regarding their collective interests in the reconversion of a brownfield site. It corresponds to an approaching and learning phase (Floc'Hlay and Plottu 1998; Gamboa 2006). To implement this, homogeneous focus groups were used with the general population (Krueger et al. 2001; Morgan 1996). At this stage of the process, elected representatives were excluded as they already had all the relevant information concerning the site, and because an in-depth interview with the mayor had already been carried out during the preliminary phase. The aim was to establish a climate of trust and to promote free discussion among the participants. This first phase prepared them for public debate and the subsequent negotiation process during the next steps.

Multiple approaches are required for appealing to potential participants and requesting they participate in a study. In our case, we sent letters, made phone calls using the directory and addresses, and posted ads (newspaper postings, flyers, and municipal ads) one month before we held focus groups. We did this to inform potential participants of the purpose of our study and what their participation would entail. A script was included for calls to recruit participants. Focus groups were formed and composed of relevant stakeholders. They were contacted using the phone book and mailing addresses of local companies and organizations.

In the autumn 2016, five focus groups were held (one group of ARUA members, one of former employees and three of members of the general population) with on average 5.4 participants per group. They lasted around one hour. This represents 27 surveyed participants. Table 2 describes the distribution of the three categories of stakeholders surveyed, along with their sociodemographic characteristics. Our sample has a balanced sex ratio. The majority of our sample consists of people who are ageing (average age = 64) and inactive –mainly retired (59.26 %). This could raise some issues concerning representativeness. Otherwise, almost half of our stakeholder sample is directly impacted (51.85%), even if the brownfield site is not visible from their house for the majority of them (64.29 %) due to the presence of the railway and a sharp drop-off terrain.

Variables	Freq.	%
Stakeholder category		
ARUA members	5	18.52
Former employees	3	11.11
General population (not members of ARUA)	19	70.37
Gender		

Male	16	59.26
Female	11	40.74
Average age (standard deviation) – min; max	64 (2.00) – 40; 80	
Employment status		
Active	11	40.74
Inactive or idle	16	59.26
Living in the Alleud neighbourhoods		
No	13	48.15
Yes	14	51.85
Among them - visibility of the brownfield from their home		
No	*9*	*64.29*
Yes	*5*	*35.71*
Total	**27**	**100.00**

Table 2 : Sociodemographic characteristics of participants from first phase focus groups

During the focus groups, participants were invited to exchange opinions in order to build a general overview of the brownfield site. They were reminded of the purpose of our study and what their participation would entail. A set of open-ended questions using maps and pictures of the brownfield was prepared. The first part was aimed at understanding stakeholders' perception of risks and their knowledge regarding previous activities and contamination. This would allow us to gain some insights into how informed they were and give further information if necessary. The second part dealt with their preferences towards the site to define relevant hypothetical scenarios. The third part covered their expectations about the scenarios defined with their help to determine criteria on which to base the redevelopment of the brownfield. To conclude, participants were thanked and given explanations regarding the next steps. In the end, these focus groups lead to the identification of hypothetical and realistic alternatives and criteria that covered the range of opinions and issues discussed.

Following empowerment, the aim of the second step is to present the different points of view for discussion. This is a negotiation process between all stakeholder categories. This step was initiated once the impacted stakeholders were ready to take part in the negotiation and decision-making processes, i.e., after we had given them information about financial constraints and level of contamination of the site for instance. This second phase was conducted with a final focus group composed of three elected representatives (the mayor and two town councillors) and six residents of the municipality who all were involved in the first phase. This final roundtable enabled alternatives and criteria elicited during the first phase of our approach to be validated.

Finally, the third step corresponds to the multicriteria evaluation, which renders participatory evaluation effective by proposing a formal framework for the development of the negotiation process. It helps to structure the problem at hand i.e., to construct a matrix-like representation of the alternatives and their performance under specific criteria identified through the focus groups. This performance table was explained and validated by participants. Weightings were obtained from each category of stakeholder identified. The outcomes were thus the result of an interactive approach, where the members of focus groups worked together to think about alternatives and criteria, and assigned values to each of the criteria they had proposed. Discussions on the consensual solutions obtained with the ELECTRE I method followed and concluded the exchanges between participants. Figure 2 illustrates the overall steps followed.

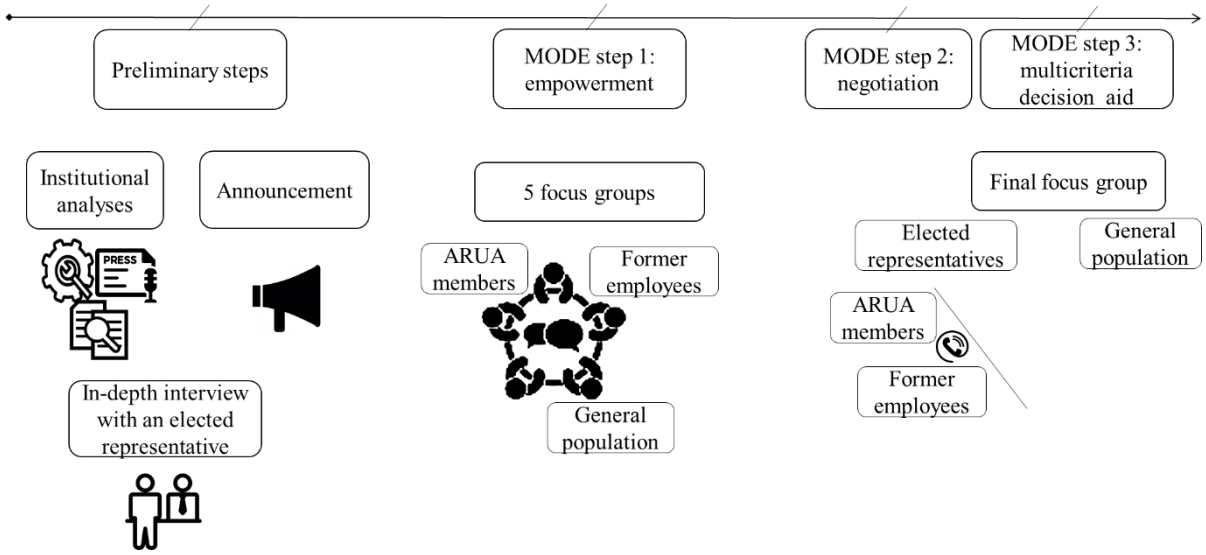


Figure 2: Framework implemented

4. Participatory Multicriteria Decision Aid Results

We will now present the results obtained through the three MODE phases. These include the results regarding perceptions of the brownfield and projects mentioned by participants (1); alternatives, criteria and their weights, which were obtained through focus groups during the two first phases (2); and the different levels of concordance and discordance that were computed to determine the most consensual alternatives (3).

1. Perceptions of the brownfield and projects mentioned: results of the first focus groups

We performed a descending hierarchical classification (DHC) using IRaMuTeQ (R Interface for multidimensional analysis of texts and questionnaires) software to analyse individuals' perceptions of the brownfield and projects mentioned during the focus groups. It provides a classification of words representing semantic contexts. We named each category according to subjects and characteristics treated. Each of these categories gathers terms that have a common meaning. We have used dendrograms to illustrate these analyses.

Participants in the focus groups perceived the brownfield site as an old industrial site (words of the second class) that was an important place of work (words of the third class). It was contaminated at the time (words of the first class) and characterized by uncontrolled vegetation growth (words of the fourth class). The dendrogram in Figure 3 illustrates this.

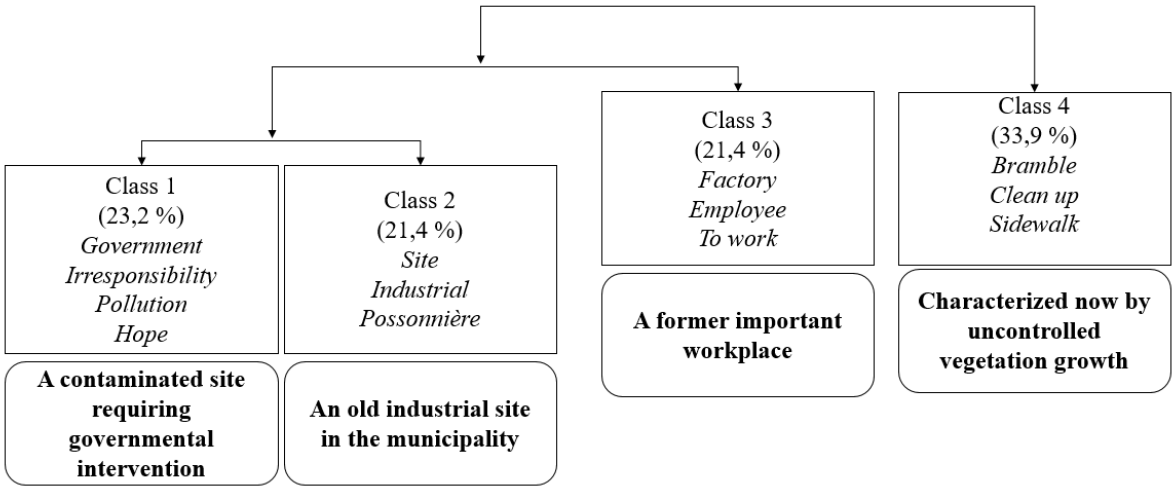


Figure 3: Dendrogram related to individual perceptions

Participants in the focus groups also mentioned numerous projects during the first phase (Figure 4). These projects were those the participants in the focus groups wanted, taking into account the constraints regarding residual contamination and the sensitivity of future uses. They also enabled us to consider stakeholder values. These projects referred to those imagined by participants, such as karting, and others they had heard about, such as a warehouse for lorries.

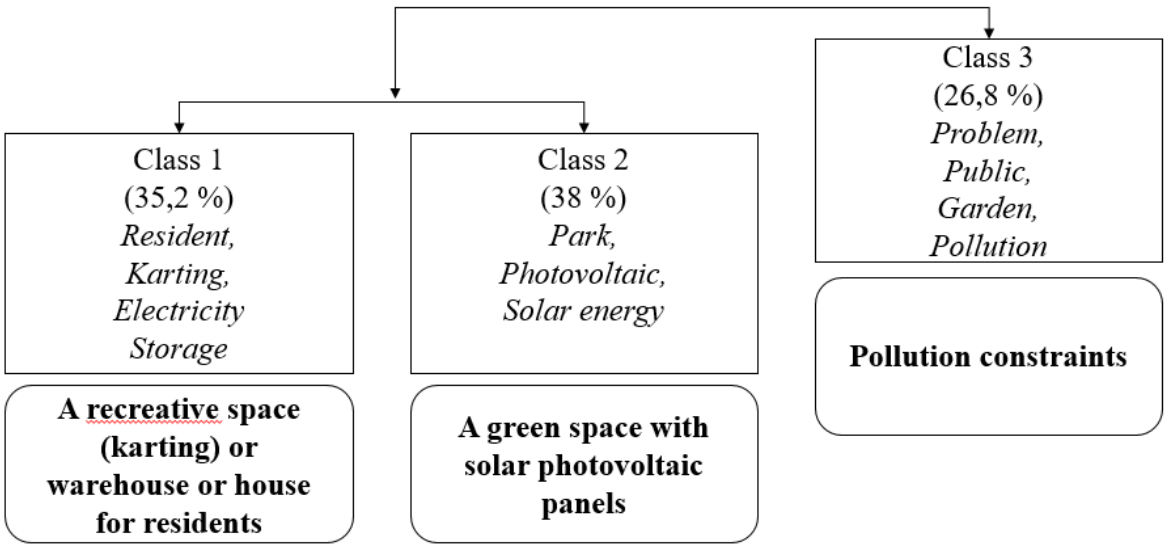


Figure 4: Dendrogram regarding brownfield redevelopment projects

2. Identification of alternatives and criteria weightings

Alternatives, criteria and their weights were obtained through focus groups during the first two phases.

Stakeholder preferences appeared to single out four projects for consideration: housing and office buildings (A_1); green spaces (A_2); storage and business (A_3); and the status quo option (A_4). The latter was an opt-out option if none of the alternatives seemed attractive enough to the participants in the final focus groups. This option concurred with the real-life decision context of respondents faced with the possibility of no buyer being willing to redevelop the site. All these projects were relevant regarding the site's constraints in the local urban plan, and possible regarding the level of contamination and future uses. These four alternatives were validated by the participants in the last two phases of our participatory process, including the elected representatives, who knew the technical and economic constraints.

A coherent set of criteria was also identified through the focus groups regarding alternatives (Figure 5).

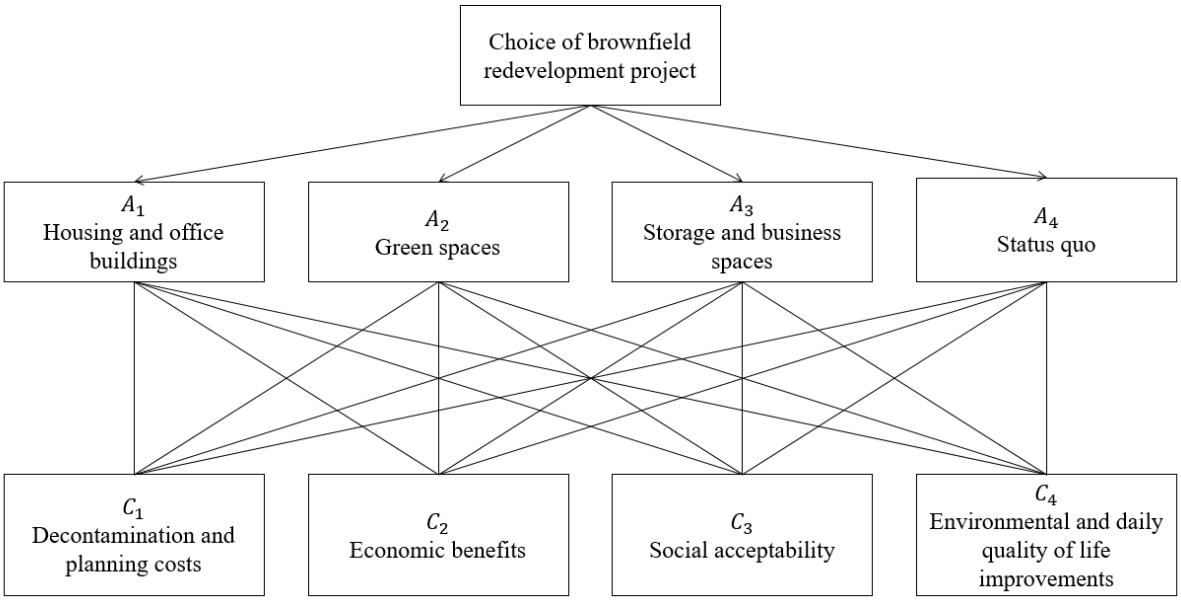


Figure 5: Multicriteria framework for our case study

Criteria reflect all concerns relevant to the decision problem, with attention paid to their exhaustiveness, cohesiveness, and non-redundancy (B Roy and Bouyssou 1993). Four criteria were identified: the costs of redeveloping the brownfield (C_1), the economic benefits (C_2), the social acceptability of the project (C_3), and the environmental and daily quality of life improvements (C_4) that site redevelopment would yield. These criteria were also validated by the stakeholders. They are described in Table 3 below.

Criteria	Unit	Objective	Principle of construction of the criteria	Description
Costs	Objective criteria in € and converted into a scale from 1 to 10 according to the weighting procedure	Min	Costs (based on ADEME files: real remediation brownfield projects) and literature review	It includes decontamination, demolition and reconstruction costs given for a brownfield redevelopment project.
Economic benefits	Objective criteria in € and converted into a scale from 1 to 10 according to the weighting procedure	Max	Property tax, council tax, rent, etc. and literature review	They express economic benefits such as job creation, supplementary fiscal resources, real estate value increase.
Social acceptability	Qualitative judgment on a scale from 1 to 10	Max	Citizenship opinion argued	It expresses the fact that the majority of stakeholders are favourable to the final decision.
Environmental and daily quality of life improvements	Qualitative judgment on a scale from 1 to 10	Max	Citizenship opinion argued	It expresses an improvement regarding environmental conditions (reduction of main sources of pollution, such as noise, and reduction of negative externalities such as the uncontrolled vegetation growth) which have an impact on the daily quality of life of the stakeholders.

Table 3 : Description of the considered criteria

The criteria were expressed on a 10-level scale. This made it easier to present the criteria to the stakeholders and help them understand the different issues at stakes. Economic benefits and costs were converted into this 10-level scale using decile ranking, with data based on ADEME files and the literature review. It is logical, for instance, that in terms of cost, the lowest cost is the most preferable. Hence, the higher the weight assigned to a criterion, the greater its importance. For example, a respondent can give a criterion a score of 10 if it seems very important to them, and 1 if not. Thus, weights are like coefficients of importance resulting from a vote procedure (Mousseau 1995). This ratio questioning technique establishes a link between the criteria based on their relative importance. Criteria weights were thus obtained using a series of cards that corresponded to 10 points to be divided among the four criteria for each category of stakeholder. Members of the focus group quickly understood the approach used to assign such weights.

Very strongly wanted	Strongly wanted +	Strongly wanted -	Wanted +	Wanted -	Unwanted -	Unwanted +	Strongly unwanted -	Strongly unwanted +	Very strongly unwanted
10	9	8	7	6	5	4	3	2	1

Table 4: Criteria notation scale

The performance table was established taking into account technical information regarding different types of brownfield redevelopment processes and their costs in France (ADEME

2012). Table 4 presents the performance of the four projects $A = \{A_1, A_2, A_3, A_4\}$ (corresponding respectively to housing and office buildings; green spaces; storage and business; and the status quo option) according to the four considered criteria $C = \{C_1, C_2, C_3, C_4\}$ (corresponding respectively to decontamination and planning costs; economic benefits; social acceptability; and environmental and daily quality of life improvements).

Criteria	Alternatives				Weights			
	A_1 – Housing and office buildings	A_2 – Green spaces	A_3 – Storage and business	A_4 – Status quo	General Population	ARUA members	Former employees	Elected representative
C_1 – Decontamination and planning costs (*1 to 10 - min*)	3	6	4	8	2	1	2	2
C_2 – Economic benefits (*1 to 10 - max*)	7	3	6	1	2	3	2	1
C_3 – Social acceptability (*1 to 10 - max*)	6	8	5	3	1	4	3	2
C_4 – Environmental and daily quality of life improvements (*1 to 10 - max*)	6	8	4	3	5	2	3	5

Table 5 : Performance table associated with alternatives-criteria and weights given by the stakeholders

Once weights were obtained we applied the ELECTRE I method using Diviz software *(Meyer and Bigaret 2012)*. It is a workbench for designing and executing MCDM using web-services. This enabled us to compute the concordance matrix for each category of stakeholder (*Table 6*) and the discordance matrix (*Table 7*) via an internet web connection. For instance, the concordance index for the green spaces projects (A_2) compared to the housing and office buildings (A_1) is equal to 0.8 as A_2outranks A_1regarding decontamination and planning costs (+0.2), social acceptability (+0.1) and environmental and daily quality of life (+0.5) criteria for the general population.

Projects	A_1 – Housing and office buildings	A_2 – Green spaces	A_3 – Storage and business	A_4 – Status quo	A_1 – Housing and office buildings	A_2 – Green spaces	A_3 – Storage and business	A_4 – Status quo	A_1 – Housing and office buildings	A_2 – Green spaces	A_3 – Storage and business	A_4 – Status quo	A_1 – Housing and office buildings	A_2 – Green spaces	A_3 – Storage and business	A_4 – Status quo
A_1 – Housing and office buildings	-	0.8	0.2	0.2	-	0.7	0.1	0.1	-	0.8	0.2	0.2	-	0.9	0.2	0.2
A_2 –Green spaces	0.2	-	0.2	0.2	0.3	-	0.3	0.1	0.2	-	0.2	0.2	0.1	-	0.1	0.2
A_3 – Storage and business	0.8	0.8	-	0.2	0.9	0.7	-	0.1	0.8	0.8	-	0.2	0.8	0.9	-	0.2
A_4 – Status quo	0.8	0.8	0.8	-	0.9	0.9	0.9	-	0.8	0.8	0.8	-	0.8	0.8	0.8	-
Category of stakeholders	General population				ARUA member				Former employees				Elected representatives			

Table 6: Concordance indexes for each category of stakeholders

Projects	A_1 – Housing and office buildings	A_2 – Green spaces	A_3 – Storage and business	A_4 – Status quo
A_1 – Housing and office buildings	-	0.3	0.2	0.6
A_2 – Green spaces	0.3	-	0.4	0.5
A_3 – Storage and business	0.1	0.3	-	0.5
A_4 – Status quo	0.5	0.2	0.4	-

Table 7: Table of discordance indexes

The aim was to select a solution that would be relatively good according to some criteria without being too bad according to others. We compared each alternative with another, criterion by criterion. Figure 6 describes the overall process applied using ELECTRE I.

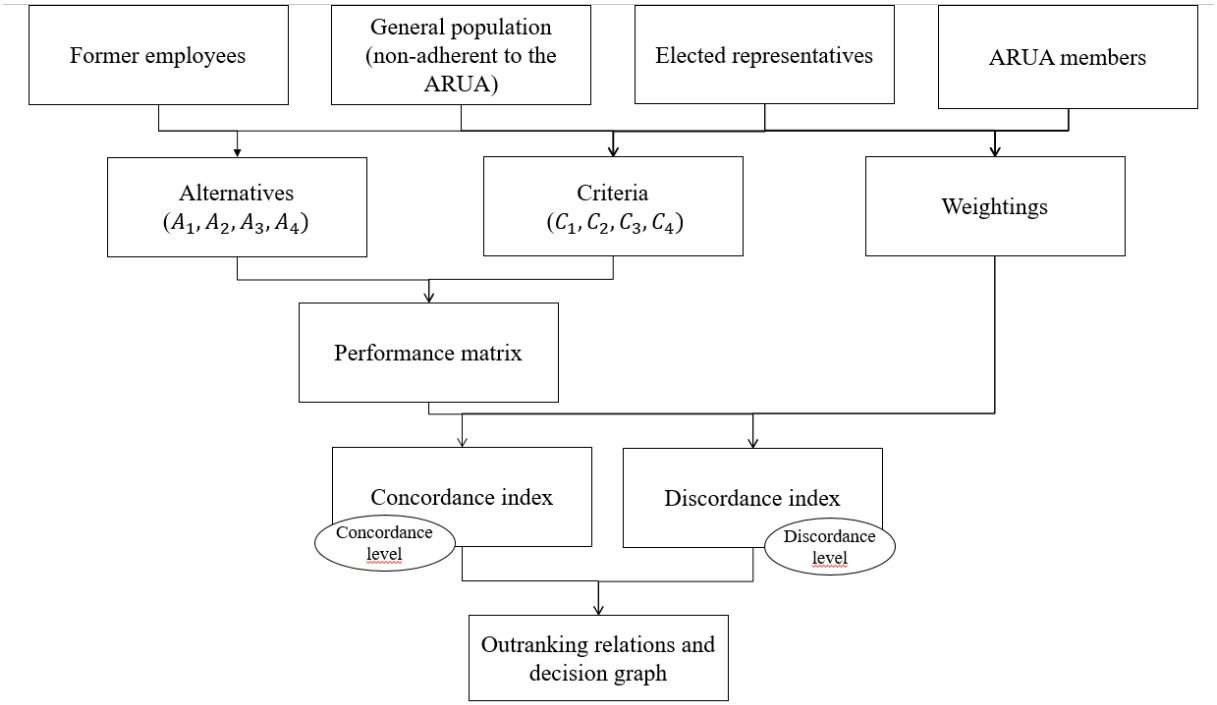


Figure 6: ELECTRE I outranking method process workflow

3. Sensitivity analyses

The final step of the ELECTRE I method is identifying the recommendations based on the outranking relations. Sensitivity analyses were performed to examine variation in the output obtained as a function of selected threshold value for the discordance and concordance indexes. To assess the stability of the results, we gradually and iteratively modified levels of concordance and discordance as illustrated by Figure 7. With high requirement levels (concordance level equal to 0.8 and discordance level equal to 0.2), we obtained the result that the green spaces project outranks the status quo option, and the offices and buildings project outranks the storage and business alternative. By lowering requirements levels, we noticed that

the green spaces alternative was still not outranked. Thus, it appeared to be the most acceptable solution for all relevant stakeholders.

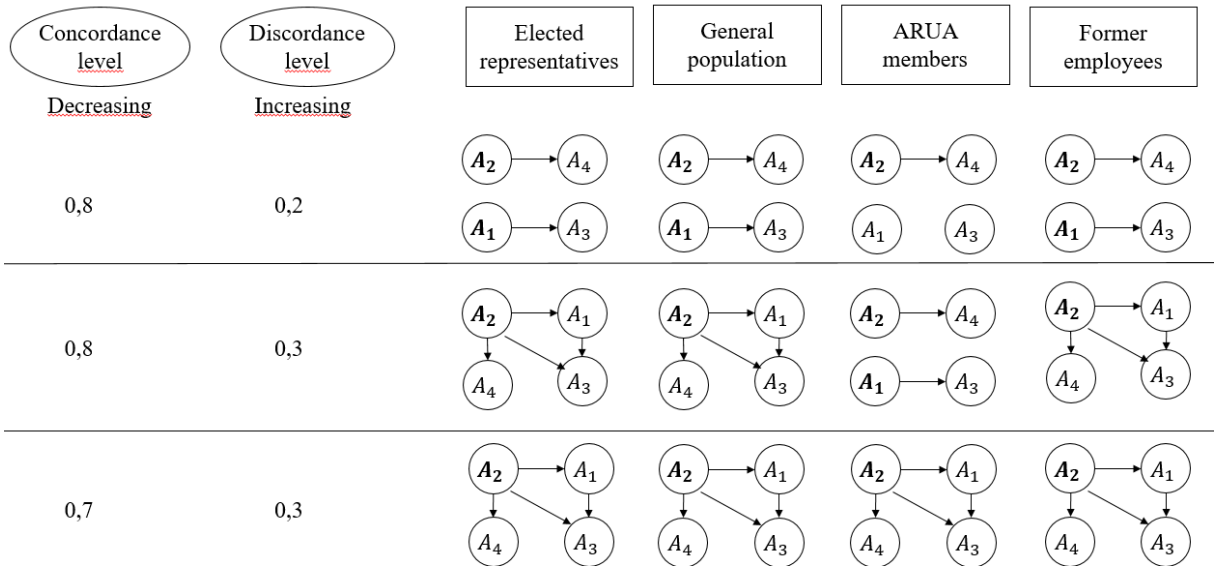


Figure 7: Results of the ELECTRE I method

All participants confirmed that the best alternative was the green spaces reconversion project.

Although an MCDA does not necessarily lead to a unique solution, it can make elements of the decision-making process more transparent and enable stakeholders to comprehend key facets related to the brownfield redevelopment process. The municipal council was very concerned about environmental issues and wanted the participatory framework and the redevelopment process to serve as an example of good practices for other contaminated brownfield sites to be redeveloped in France.

5. Discussions

Recent attempts to design a participatory framework in the case of contaminated sites have been proposed in the context of mining requalification (Mateus, Bana e Costa, and Matos 2016). Mateus et al., (2016) implemented MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) participatory tools with ten experts in the context of the rehabilitation of an open-pit mine site in the village of São Domingos (Portugal). Morio et al., (2013) proposed an integrated planning and assessment of brownfield redevelopment options with respect to sustainability indicators for a former military site located in Potsdam (Germany) and using a panel of experts. These attempts show the need to go further in the development of an integrated participatory framework in the case of contaminated sites by including all relevant stakeholders, such as laypeople. We bridge this gap by showing how such a participatory process could be applied.

Multicriteria analyses also avoid the many limitations of a mono-criterion approach, such as a cost-benefit analysis. Indeed, they are able to incorporate a wide range of criteria, both

quantitative and qualitative, without requiring unit normalization. Thus, they do not systematically require a monetary valuation of these criteria as well as a conversion of the original scale into an abstract and arbitrary one. Hence, outranking approaches, such as ELECTRE I, are powerful tools to deal with different components of a value that may involve subjective and sometimes incommensurate criteria, such as existence value (E. Plottu and Plottu 2007), as may be the case with brownfields (Bliek and Gauthier 2007). These methods are also able to deal with potentially conflictual criteria or objectives. Thus, they create a structure to help in decision-making (B Roy and Bouyssou 1993, 200; J. R. Figueira et al. 2013).

Furthermore, participatory approaches in the form of focus group techniques or content analyses, for instance, highlight the way weightings are obtained. Weights are like coefficients of importance resulting from a vote procedure (Mousseau 1995). Consequently, it enhances the transparency and pluralism of decision-making processes (Xenarios and Tziritis 2007), which is fundamental to avoiding conflict in urban planning management.

The ELECTRE I method is quite simple to implement and easy for stakeholders to understand during a participatory process. The logical stringency of MCDM does not obstruct the social dynamics of a deliberative process. An MCDM procedure, as an iterative procedure, allows for changes resulting from learning (Vatn 2009). Although, the subjective nature of criteria may be discussed, it reflects the social reality and daily experience of participants

This experience also demonstrates individuals are capable of reasoning in terms of collective utility (Sagoff 1998). At first glance, participants perceived the site as contaminated., However, following a participatory approach, participants worked together to find consensual solutions for redeveloping the site.

Results show that social acceptability and environmental and daily quality of life improvements are the two main criteria that should be take into account. This conclusion is similar to results obtained by other studies using questionnaires regarding the most important criteria to take into account in redeveloping a brownfield (De Sousa 2006; Kunc et al. 2014; Turvani, Tonin, and Alberini 2010).

To conclude, applying our framework shows that a structured and flexible participatory process using mixed approaches is useful for contaminated brownfield management assessment. Results obtained could be of greater relevance to policy-makers as the main advantage of our method relies on its flexibility. It is relatively easy to modify the main components of the decision problem for different case studies and to present results obtained to relevant stakeholders. Therefore, our decision support framework is also a good instrument for providing data for negotiation and decision-making applied to other environmental problems that require public participation.

6. Conclusion

We designed and applied a participatory process to support a decision-making process regarding brownfield redevelopment. It relied on the identification of stakeholders and the comprehension of the context in which the brownfield site was embedded (Kontogianni et al. 2001) and followed the three fundamental steps of MODE (Floc'Hlay and Plottu 1998).

This framework enabled stakeholders to be aware of the existence of a common interest and federated them towards a collective project of redevelopment. Application of our framework showed that a structured and flexible participatory process using mixed approaches is useful for contaminated brownfield management assessment. This participatory process enhanced the

decision by incorporating elements that had been proposed by stakeholders. The results obtained were possibly of greater relevance to policy-makers. They demonstrated that social acceptability and environmental and quality of daily life improvements were the two main criteria that should be taken into account according to participants of focus groups. All participants confirmed that it was coherent with their expectations. Moreover, this application offered a space for dissemination of research results and mediation regarding soil contamination. These results were obtained following an interactive approach requiring participation and interaction between participants of the focus groups, who worked together to find a way to redevelop this brownfield site.

To conclude, the way the whole work has been conducted, the nature of the obtained results and their acceptability serve to validate the use of our methodological framework as an aid for making better decisions in this type of context. Future research projects could focus on the use of a veto to take into account constraints with respect to easements due to the level of contamination, for example, to enhance public recommendations under time and resource-pressured conditions.

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Supplementary data

Steps	**Duration (estimated)**	**Introduction**
	10 min	*Presentation of the researchers and objectives followed*
Presentation	« Hello everyone, thank you all for coming. I am … ; I am a PhD candidate at the Agrocampus Ouest in Angers, and I work on brownfield redevelopment. Here is … who is my PhD advisor…	
Objectives of the focus groups, rules of the game and recording agreement	As part of my course, I’m interested in the brownfield site of the SAPEMO-SAITS located in the district of Alleud. We have scheduled two meetings to exchange with all relevant stakeholders regarding this site: residents, members of ARUA, former employees and elected representatives. Today, in this first meeting, which you are taking part in, we will discuss the characteristics of the neighborhood and future uses to identify various issues associated with the brownfield site, and which should be taken into account in the context of a hypothetical redevelopment project. I would like to point out that no reconversion project is planned at the moment (either by the municipality or by a private developer). The goal is that you exchange ideas about the site. You have to talk to each other. We are here to facilitate your exchanges, to refocus the discussion if it drifts away from the topic, and to allow each of you to express your point of view. Please take care not to interrupt each other so that the entire group can hear your comments. There are no right or wrong answers.	

	The approach we are taking and the data we are collecting will be used exclusively for research purposes. Your comments will remain confidential and anonymous. If everyone agrees, we will record the discussion so that we can faithfully transcribe your remarks and analyze them more easily thereafter. We will not use your name and surname in our reports and will destroy the recording after the interview has been transcribed. Do any of you object to the recording?	
	Start recording if all participants agree – intensive note-taking otherwise.	
Roundtable	As you can see, there are table *number* cards. This number corresponds to a unique identifier. It will allow us to ensure that the documents you fill in remain anonymous. It is important that you write this number on the various documents, like the presentation sheet, that will be distributed to you.	
	Presentation sheet distribution (gender, age, employment status, profession, number of years of residence in the municipality, whether living or not in the Alleud neighborhoods and if yes, whether the brownfield site is visible from their home) – collect them once they are completed (check the ID or add it).	
	I suggest that each person introduces himself/herself to the others around their table by indicating his/her name, surname, number of years of residence in the municipality and whether or not he/she is living in the Alleud area.	
No.	**Duration (estimated)**	**Perceptions and knowledge of the site**
	10 min	*Distribute the "perceptions SAPEMO" sheet*
1	First, I want you to think for a few minutes and indicate on the paper distributed to you what comes to mind when you hear of the SAPEMO or SAITS site; which words or sentences come to you spontaneously when you hear about the site.	
Roundtable of answers – press releases if necessary about water and soil contamination.		
2	Do you know what activities were carried out at the site in the past? What are they?	
Roundtable – photographs of past activities and press releases if necessary.		
No.	**Duration (estimated)**	**Building map of the logico-hierarchical evaluation**
	10 min	*Map of the site*
3	This map represents the cadaster of the brownfield site and its neighborhoods. As you can see, there is the SNCF railway to the north in brown. If you focus your attention on the site only, from your point of view, is there built or unbuilt element on the site that should be destroyed or removed in view of a future brownfield redevelopment project? + Roundtable.	
4	In contrast, are there any built or unbuilt elements that should be saved, that should be kept or improved or refurbished in view of a future brownfield redevelopment project? Could you explain why? + Roundtable.	

No.	Duration (estimated)	Preferences for brownfield redevelopment projects and criteria
	20 min	*Distribute the map*
5	[Plan A] We are going to continue thinking about future uses. As you have indicated some elements to be demolished and others to be kept, have you already thought about new projects that could be implemented at the site? What are these projects? What strengths and constraints could these projects generate?	
Specify and explain contamination constraints if necessary.		
5	[Plan B if discussion is not forthcoming, suggest some hypothetical brownfield reconversion projects] I'm going to give you some examples of projects that have been made for other brownfield sites similar to this one *First slide* In this case, green spaces were created and phytoremediation techniques were used to decontaminate the site. What do you think about this project? *Second slide* In this second scenario, the brownfield has been reconverted with an office, buildings and houses without basements. What do you think about this project? What do you think about this project compared to the first? *Third slide* Another alternative could be an industrial use. What do you thing about this project? *Fourth slide* Brief summary of the different scenarios proposed.	
6	Now I propose you discuss the criteria on which a reconversion project for this site should be based. Please think about criteria on which the redevelopment of the site should be based; write them on the form. *Gather forms and roundtable.*	

Duration (estimated)	Preliminary results
5 min	Present some preliminary results

Duration (estimated)	Acknowledgements and what's next
5 min	

This meeting you have been attending includes other stakeholders. I invite you to fill in the form to indicate your availability for a second meeting in which you are going to talk about the results obtained by our approach, and think about a brownfield redevelopment project with elected representatives. Please give a telephone number and/or e-mail address so that we can contact you and inform you of the date for this next meeting. Thank you all for your participation.

Figure 8 : Word cloud associated with individual perceptions regarding the brownfield site [Some of the most frequently used words are: to put, to work, brownfield, to clean up, Possonnière, State, common, Possonnière, Sapemo, industrial, house, dairy, smelting plant, municipality. Some of the less frequently used words are: bramble, irrresponsibility, vandalize, owner, business, vegetation, hope, dangerous]

Figure 9: Word cloud associated with the projects mentioned by participants. [Most frequently words: resident, site, park, lorry, pollution, pollute, karting, garden, factory, bike, nature, reed, electricity, idea, etc.]