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Integrating Cognitive Mapping Analysis into Multi-Criteria Decision Aiding

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Abstract

Multi-criteria decision aiding (MCDA) is a process implying two distinctive actors (the client and the analyst) which aims at providing transparent and coherent support for complex decision situations, taking into account values of decision makers involved in a specific decision context. The theoretical framework of MCDA traditionally addresses problems involving a single decision maker. However, MCDA ought to investigate the case where the decision maker is made up of groups of individuals with conflicting interests. In contrast, cognitive mapping (CM) is frequently used in order to capture the values in a group of individuals and to reduce the antagonism between such values. Its ability to capture multiple values and reduce their conflicting aspects provides a rationale for decision problem analysis with multiple stakeholders. Nevertheless, capturing values by CM is not always intended for a subsequent multi-criteria analysis.

This paper explores the integration of both techniques combining their respective strengths as well as their application in assessment of hydrogen technologies scenarios in terms of their perception and social acceptability by the general public.

Keywords: Hydrogen technologies; Social acceptability; Problem structuring; Cognitive mapping; Value trees of objectives; Multi-criteria decision aiding.

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1. Introduction

The work report on this paper is conducted within the context of the AIDHY project, in which distributed expertise on hydrogen technologies is brought together to address the issue of the social acceptability of hydrogen technologies scenarios. Power planning marked by the predicted decline of fossils fuels and the need for consideration of environmental concerns and energy independence, lead governments to think in terms of energy mix. The term energy mix refers to the distribution, within a given geographical area, of energy originating from various energy sources (crude oil, natural gas, coal, nuclear energy, and renewable energy). It depends on (i) the availability of usable ressources (possibility of local or import ressources), (ii) the extent and nature of energy needs to be meet, (iii) the social, economic, environmental and geopolitical context and (iv) the political choice resulting from the previous points. As a result the choice of energy mix is a complex decision with important consequences in society. Different energy mix will require different types of energy carriers for effective transformation, storage and consumption. This resulted in developing new technologies about energy carriers such as the hydrogen. To ensure that energy using such new technologies is not rejected, a study of social acceptability must be conducted. The decision makers face a complex situation, since assessing hydrogen technologies involves the evaluation of many conflicting objectives, expression of various multiple stakeholders. This decision context is even more difficult because of its social dimension. This difficulty is particularly important when the social group is extended to the general public, which by definition consists of heterogeneous opinions. Since the sum of individual rationalities does not necessary lead to a collective rationality it is unlike that consensus self-emerges. Hence the necessity to study the problem of the legitimacy of the decision and its acceptability by the stakeholders.

In order to face the particular complexity of decision problems in such contexts, Munda [43] suggests a methodological framework called *"Social Multi-criteria Evaluation"*. This methodology emphasises uncertainty and significant conflicts of values, an issue specific to public decision processes. In addition to a technical dimension of uncertainty, which is quantitative and relative to the inaccuracy of the parameters and can be apprehended by tools such as sensitivity analysis, robustness and Monte Carlo methods, it offers three other dimensions: (i) a methodological dimension which is related to the reliability of the methods used , (ii) an epistemological dimension which is linked to the lack of knowledge w.r.t the problem studied and (iii) a social dimension due to the *"social mess"* [25]. In the latter case of social uncertainty, decisions are not completely determined by scientific facts (see also [38]). Assuming that a good decision involves a socio-technical process, scientific arguments can be debated by the arguments based on the values of the actors. The actors being taken into the sense of socio-economic public and private stakeholders. This is for instance the case of the hydrogen scenarios assessment when it comes to evaluate technologies scenarios, based on scientific expertise and taking into account the values of the general public.

Multi-criteria decision aiding (MCDA) is often chosen as the basis for decision support systems in prospect of energy issues (see [41], [42], [53]), since MCDA aims at providing transparent and coherent support for the comprehension of complex decision situations with possibly conflicting objectives. Typically, depending on the approach or a combination of approaches adopted (Normative, Descriptive, Prescriptive, or Constructive) [55], a decision aiding process consists in producing four cognitive artifacts: (1) a representation of problem situation, (2) a problem formulation, (3) an evaluation model, and (4) a final recommandation [55]. Many MCDA evaluation models are based on deterministic evaluations of the consequences of each alternative on each attribute in relation to the views of a single and specific decision maker. Traditional evaluation methods have difficulties solving problems involving several possible decision makers with potentially conflicting objectives. Hence, mechanisms that guarantee for the consistency of the problem situation and its development should be included. Another problem is that there are no features inherent in classical MCDA allowing to capture values for more than one decision maker or considering social uncertainty in public decisions. Under such a perspective there are substantial benefits to be expected from a framework that integrates Cognitive mapping (CM) into MCDA going beyond from social choice inspired methods or from methods eliciting sound trade-offs (see [8], [9]).

Cognitive mapping has been applied predominantly in psychology and behaviourial sciences [29], management (see [19], [12], [21], [36], [37], [50], [56]), politics (see [2], [20]), economics (see [11], [35]) and other areas (see [39], [40]). Although CM have been initially fit for individual decision making representations, they are nowadays mainly used to support group decision contexts where one should consider judgments of experts and group participation in an environment (focus groups) that fosters creativity. A prime aim of cognitive maps is to graphically represent the ideas of a group of individuals through a network of interrelated concepts. Cognitive mapping allows to build a shared vision of the decision problem and facilitate the identification of values and their conflicting elements that may have an impact on the consequence of decision [18]. The way cognitive mapping allows to deal with values differs from conventional methods. These usually present one single decision maker objectives, including his values and interests in terms of criteria and preferences. Instead, cognitive mapping address complexity by presenting several stakeholders objectives that encompass all their relevant values, so as to reach a cluster of consensual values through *"negotiation of ideas"* [12] between individuals. In addition, the design of cognitive maps through the interactive setting of focus groups is likely to be attractive to stakeholders, for it provides additional means of decision legitimacy by ensuring transparency and participation. Cognitive mapping indeed provides support for mapping the participation of multiples stakeholders as shown in the methodology proposed by Damart [13].

The paper is structured as follows: Section 2 starts with a brief outline of MCDA illustrating how MCDA methods can be applied. Then the analysis of cognitive maps and the structuration of a decision problem on the basis of cognitive mapping findings are explained. Subsequently, the problem of cognitive maps items conversion into value tree for objectives by clustering them under High-level and lower-level hierarchically is considered. We demonstrate how a judicious choice of graphical models can facilitate this conversion. Then, an example for the AIDHY project is introduced to highlight the key points of our approach. The last section gathers conclusions.

2. Value trees and problem structuring

According to Simon [52], decision making is a process consisting of three main stages: (1) Intelligence, (2) design and (3) choice (see Fig. 1). In the intelligence phase, we try to determine if the problem to face requires a decision. Simon considers the design step as the true structuring phase of the problem since it allows the identification of alternatives, criteria and attributes. However, following the authors of the so called "soft operational research" (for a discussion, see the opposition between Soft Operations Research (OR) and Hard Operations Research in [10], [48]), we consider that the intelligence stage is an integral and most important part of problem structuring because it prevents type III errors: defining the wrong problem, leads to the wrong solution (see Raiffa [47]). Many other authors also focus on this crucial phase of decision analysis as a starting point for problem structuring (see [8], [16], [48], [55]).

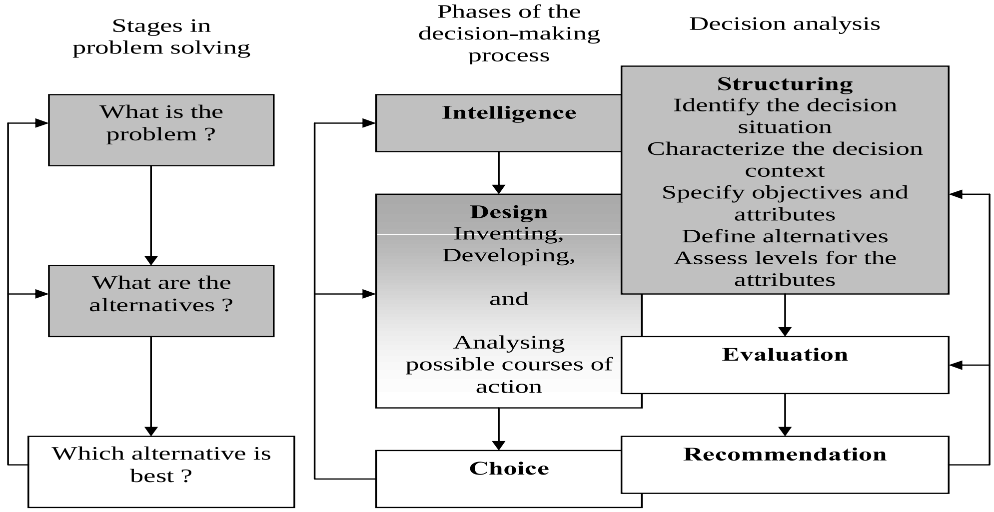

Figure 1: General framework of decision analysis. Sources: Galves [23]

From Figure 1, we can see that the results of structuring is an input to a multi-criteria evaluation model. This necessary link between the structuring and evaluation model has been the subject of numerous studies (see [4], [39]). Since for most MCDA evaluation models the criteria are deduced from the objectives, the later have to be elaborated and made clear. Using the principles of value-focused thinking proposed by Keeney [28] seems adequate in order to address this issue. These principles allow to specify objectives in terms of decision-making context, purpose and preferential direction. Objectives are statements of something that one desires to achieve. According to Keeney [28], objectives are characterised by three features:

- decision context
- object
- direction of preferences

For example, two objectives for power planning decisions could be to minimise costs and to maximise security. For the former objective, the decision context could be the choice of a good power plan, the object is costs for a chosen plan, and less costs are preferred to more costs. For the last objective, the decision context remains the same, the object is systems' security for a chosen plan, and more security is preferred to less security.

For decisions using multiple attributes, Keeney and Raiffa [27] propose to structure the decision maker's objectives, beginning with defining their area of concern, which must provide a formal specification of these objectives, so that multiple points of view are comprehensively considered. Keeney [28] distinguishes two types of objectives: the fundamental and the means objectives. He states the difference as follows: on the one side, *"The fundamental objective characterises an essential reason for interest in decision situation"*; on the other side, *"A means objective is of interest in the decision context because of its implications for the degree to which another (more fundamental) objective can be achieved [...]"*

For example, higher control system may appear to be an important objective, but it may be seen important only because it would allow a plan to increase its security standards. Thus, higher control system could be seen as a means objective and increasing security standards as a fundamental objective.

In traditional MCDA methods, structuring objectives (assuming the perspective of an evaluation) results in a value tree hierarchy of objectives referring to the fundamental objectives hierarchy and criteria associate with it (cfr. an illustrative example in Figure 2). This is a three level value tree 3-level value tree of fundamental objectives. The construction of such fundamental objectives is based on a top-down approach. In this approach the overall fundamental objective is identified, then it is detailed into more specific objectives. The decomposition of objectives is carried out iteratively until a sufficiently low level, that can be associated with an attribute or a measurable criterion, is reached. This type of representation of decision-making structure has been used by many authors and applied effectively in many studies (see [1], [5], [44], [46], [49], [51]) particularly in the field of energy issues (see [26], [45]). In order to help the structuring of objectives, Belton et al.[3] propose the use of cognitive mapping [19] which we develop in section 3 .

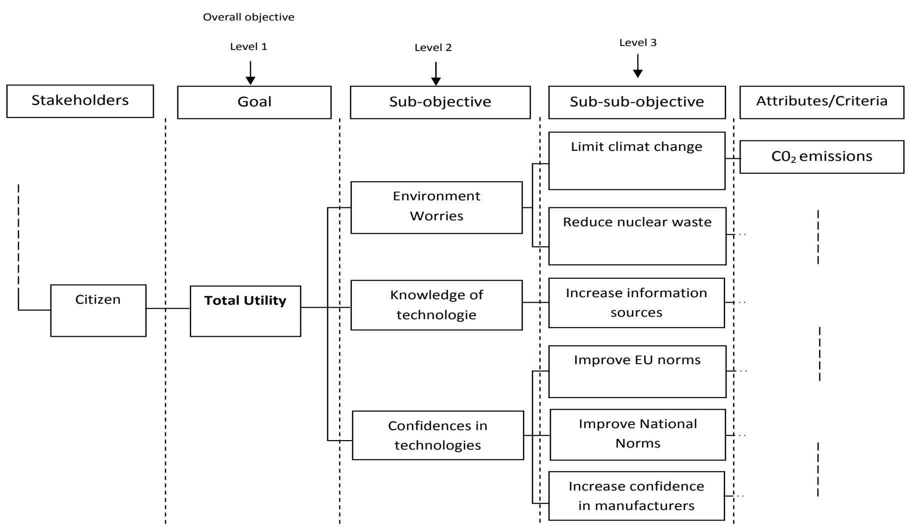

Figure 2: Illustrative 3-level (partial) value tree of objectives. Sources [34]

3. Cognitive mapping (CM)

In traditional MCDA setting, two individuals, the decision maker (DM) and the analyst interact with respect to a problem situation. This interaction is intended to help a decision-maker to structure his ideas for handling the problem that he faces. An informal dialogue between the decision maker and the analyst may be sufficient in the case of a single decision maker. In the case of multiple decision-makers or group of stakeholders, this task becomes much more difficult. On the basis of former works about animal psychology [54], human psychology [29], or strategic choice approach [22], Bougon [7], Eden [19], Ackermann [19] and Komocar [30] proposed a more formal tool for this kind of interaction: cognitive mapping (CM). The general idea of cognitive mapping is to graphically represent the ideas of a group of actors through a network of concepts and possible causal links. A cognitive map is co-constructed by the participants and the facilitator in a format that is viewable by all participants in the focus group (cf. section 1). These groups aim to promote open discussion among participants and stimulate their imagination to make them produce the most ideas in the shortest possible time (brain-storming). The facilitator is the person responsible to conduct and supervise the discussion in a group of approximately fifteen individuals. The

CM activity can be conducted through a focus group conversational mode. Focus groups are a special type of group used to gather information from members of a clearly defined target audience. Such audience is composed of six to twelve people who are similar in one or more ways, are guided through a facilitated discussion, on a clearly defined topic to gather information about the perceptions, opinions, beliefs, etc. of the group members.

CM is generally used in a process of decision support for defining a problem through a *"network of explanations and consequences associated with a unique situation"*[12]. Its visualisation *"helps to think, explore and transform or confirm more or less shared ideas"*. In this sense it can resolve conflicting objectives through *"negotiating ideas"* between individuals. Beyond the interest to tell what the problem is, we will focus on analysis and exploitation of its contents for purposes of structuring a multi-criteria analysis. In our study, this implies to consider cognitive maps not as a goal but as a mean. For this purpose we will retain the following definition: *"cognitive map is a graphical representation of the mental representation that the researcher [facilitator] gets from a set of discursive representations expressed by a subject from its own cognitive representations, about a particular object"*[12].

Several graphic forms that adopt different conventions have been proposed by Bougon and al [6], Axelrod [2] and Eden [18] in order to represent cognitive maps (see Fig. 3, 4 and 5).

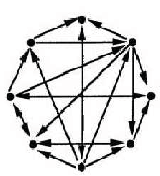

Figure 3: Graphical form used by Bourgon. Sources: [18]

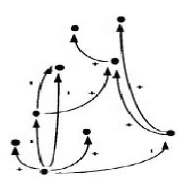

Figure 4: Graphical form used by Axelrod. Sources: [18]

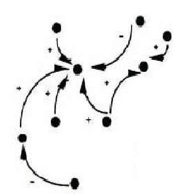

Figure 5: Graphical form used by Eden. Sources: [18]

Example 3.1. *Figure 6 represents a partial cognitive map using Eden[18] convention describing the acceptance of H_2 powered cars by a group of individuals. More details and explanation about this map will be given in the* *next subsection. At this level, we will only present an overview of this map. Indeed, it is part of a cognitive map constructed by interaction with a group of individuals who expressed their views on the issue of hydrogen (see [34]). In the next section, we will return to this example to demonstrate the potential of such a representation regarding its possible transformation into a value tree, particularly that of stakeholders objectives. Our goal is to provide a consistent methodology for moving from one representation to another one in a process of multi-criteria decision aid involving groups of individuals rather than a single decision maker.*

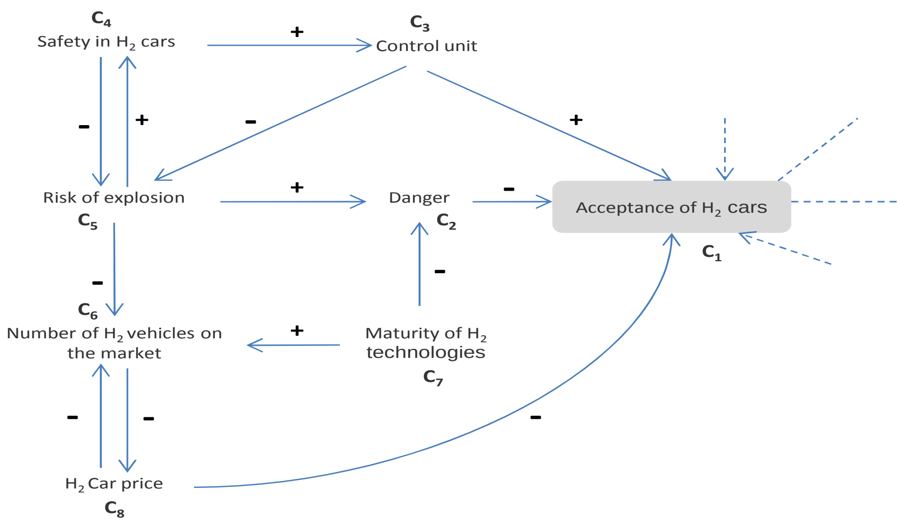

Figure 6: Illustrative (partial) cognitive map on H_2 powered cars. Sources: [34]

4. Conversion of cognitive maps in value trees

The conversion of cognitive maps in value trees can be based both on the physical structure of these graphical representations and their semantic aspects. Here, we first present briefly the theoretical framework underlying this conversion, then we propose handling practices to reflect the characteristics of these graphs in terms of a decision-aiding context.

Theoretical approach

Formally, the two objects that are the subject of this section ie, cognitive maps and value trees, are graphs; the former being a simple graph and the last being a particular type of graph. Many textbooks provide a broad development of this objects in graph theory (see [15], [24], [57] and [17]). To apply the graph formalism in our model, we propose the following definitions:

Definition 4.1. *A directed graph (also called digraph) is an ordered pair of sets $G = (\mathcal{V}, \mathcal{A})$ where $\mathcal{V} = \mathcal{V}(G)$ is a set of vertices and $\mathcal{A} = \mathcal{A}(G) \subseteq \mathcal{V}(G) \times \mathcal{V}(G)$ a set of arcs consisting of ordered pairs of vertices of $\mathcal{V}$.*

Definition 4.2. *A digraph is said to be connected if there is path (an alternating sequence of vertices and arcs, beginning and ending with vertices, with no repeated vertices), between any two vertices.*

Definition 4.3. *A **cognitive map** (CM) is a connected digraph $CM = (\mathcal{C}, \mathcal{A})$ with concepts like concerns, objectives, events, key issues, ideas, or/and opinions as vertices ($\mathcal{C}$) and relationships between concepts as arcs ($\mathcal{A}$). Here a CM digraph is loopless, i.e $\forall u \in \mathcal{C}$, $(u, u) \notin \mathcal{A}$.*

Concepts represent ideas, opinions and key issues an individual or group of individuals associate with the investigated issue. For example, in our case, in cognitive maps capturing the perception and social acceptability of hydrogen technologies, concepts represent key issues and main options a specific group of individuals associated with the idea of hydrogen technologies and their consequences. As we state in definition 4.3, concepts on cognitives maps may be heterogeneous items (e.g concerns, opinions, ideas, etc.). In addition, cognitive maps capture in a hierarchical format (although inaccurate, imprecise and biased) how an individual explains its perspective, and why situations (strategic issues) might matter for the strategic future of an organisation (eliciting goals, objectives, values).

Thus we can derive from the CM digraph, a connected subdigraph denoted by $C_oM = (\mathcal{O}, \mathcal{A}_o)$ where $\mathcal{O} = \mathcal{O}(C_oM)$ represents a set of stakeholders objectives derived from the initial set of concepts $\mathcal{C}$ ($\mathcal{O} \subseteq \mathcal{C}$) and $\mathcal{A}_o$ the corresponding subset of $\mathcal{A}$ consisting of ordered pairs of objectives so that $\mathcal{A}_o = \mathcal{A} \cap (\mathcal{O} \times \mathcal{O})$.

Definition 4.4. *An arborescence with a vertex r called the root is a subdigraph $T = (\mathcal{V}', \mathcal{A}')$ of digraph G which does not contain a paire of opposite arcs (no cycle) and such that the following conditions hold: (i) if the directions of arcs are ignored, then T is a spanning tree; (ii) there is a path from r to every other $u' \in V'$*

Thus a **value tree** of objectives (VT_o) is an arborescence whose root is the overall objective.

Given these definitions, the question is under which conditions we can move from a graph representation (C_oM) to a tree representation (VT_o) in accordance with the objective of our study. The following lemma gives us a tool to effectively address this issue.

Lemma 4.1. *C_oM contains an arborescence VT_o if an only if each vertex in C_oM is reachable from r. Where r is a vertex called root and there is a path from r to every other vertex $v \in \mathcal{O}$.*

To prove this lemma, we recall the following definition (see [57]):

Definition 4.5. *A spanning tree T of a graph G is a subgraph of G containing all the vertices of G such that $V(T) = V(G)$. Where $V(T)$ (respectively $V(G)$) is the set of vertices of T (respectively of G).*

Proof 4.1 (Lemma 4.1). *proof of "$1 \Longleftrightarrow 2''$:*

$1 \equiv C_oM$ contains an arborescence VT_o ; $2 \equiv$ each vertex in C_oM is reachable from r.

***(a)** proof of "$1 \Rightarrow 2''$: assume that the direction of arcs is ignored in C_oM (without loss of generality) and that C_oM contains an arborescence VT_o, hence VT_o is a spanning tree (cfr.(i) in definition 4.4) and $V(VT_o) = V(C_oM)$ (cfr. definition 4.5), from theses consequences, the conclusion is straightforward: each vertex in C_oM is reachable from any vertex in the spanning tree VT_o, since there is no cycle (cf. definition 4.4). In particular each vertex in C_oM is reachable from the the root r of the spanning tree.*

***(b)** proof of "$1 \Leftarrow 2''$: assume that each vertex in C_oM is reachable from r, hence there is (i) a path from r to any other vertex $u' \in VT_o$, a subgraph of C_oM ; and (ii) VT_o has no cycle.*

(i) and (ii) $\Rightarrow VT_o$ is a spanning tree , hence VT_o is an arborescence contained in C_oM. □

The consequence of this lemma is that, by construction, a cognitive map still contains an arborescence since the main concept is the root from which all other concepts are directly (strongly connected) or indirectly (weakly connected) related.

Within this formalism, the transfer of CM into a value tree follows some rules. Since graphs can have closed circuits, this transfer is achieved by "meaningfully" ($\mathbf{R_1}$)opening the circuits by either duplication of one of its vertices (which may contain more distinctive information) or ($\mathbf{R_2}$)merging two or more vertices (which may contain redundant information). This transfer patterns, using graph theory, and the previous rule will be illustrated by a real-world case study in section 5.

Practical approach

To consider a conversion from cognitive maps to a value tree of objectives, a set of features should be identified between the two graphs. These may be differences or similarities such that by a minimum of simple manipulations, we can move from one graph to another and possibly vice versa. In general, the concepts are represented by circles connected by arrows indicating the presence and direction of the relationship of influence between them. In some cases, the direction of the link when it exists, is represented by the signs (+) or (-) indicating a positive or negative correlation. It appears that the graphical formalism to draw a cognitive map is not always the same. Depending on the chosen formalism, a graphical representation can be more or less adapted to a given problem. If the modelling of the decision problem is oriented to the construction of an evaluation model, therefore based on the principle of value tree of objectives, the formalisms of Axelrod [2] and Eden [19] are more suitable. According to these graphical formalism and the value tree features (see section 2), we propose to articulate the transition from cognitive maps to value trees through the following matrix connecting them (see Table. 1):

Key transfer points	**Cognitive Map**	**Value Tree**
Objet	*Concepts*	*Objectives*
Starting point	*Central concept*	*Overall objective*
Structure	*Relational*	*Hierarchical*
Type of relation	*Influence*	*Top-down*
Nature of relation	*Correlation*	*Preferential*
Direction	*Positive/Negative*	*Maximize/Minimize*
Stakeholders	*Multiple DMs*	*Single DM*

Table 1: Matrix connecting items between value tree and cognitive map

The connection between the two graphs is a table of equivalences, which allows the transition from cognitive maps to values trees of objectives. Following such equivalences, the conversion between the two graphs becomes possible. The two graphs are differential graphical representations of similar underlying mental operations, assuming that all the concepts are the objectives, such operations being conducted to gather informations. With some manipulations, a cognitive map of the type Eden [19] or Axelrod [2] suggested, can be drawn as a value tree. Depending on the problem on hand, Axelrod cognitive maps can also be used to directly evaluate options by modelling them as fuzzy cognitive maps (FCM). The discussion of this approach is beyond the scope of this paper, but it can be found e.g in ([31], [32], [33]).

Example 4.1. *Let consider again the acceptance of H_2 powered cars given in example 3.1 and its derived cognitive map (see Figure 6).*

According to definition 4.1, the cognitive map in Figure 6 is a signed digraph $CM = (\mathcal{C}, \mathcal{A})$ with circuit $(c_5c_4c_3)$ where $\mathcal{C} = \{c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8\}$ is a set of concepts, $\mathcal{A}= \{(c_2, c_1), (c_3, c_1), (c_8, c_1), (c_5, c_2), (c_7, c_2), (c_3, c_5),$ $(c_4, c_3), (c_5, c_2), (c_5, c_4), (c_5, c_6), (c_6, c_8), (c_7, c_8), (c_8, c_6)\}$ are relation of influence between pairs of concepts and P_+(respectively P_-) the positive (respectively negative) polarities of the edges.

The polarities are attached to the following meanings:
($\mathbf{R_3}$): c_5 has a positive influence on c_2 i.e more c_5 implies more c_2, hence the following proportional relation for any two concepts i, j :

$$(iP_+j) \Longrightarrow (c_i \nearrow) \wedge (c_j \nearrow) \tag{1}$$

($\mathbf{R_4}$): c_2 has a negative influence on c_1 i.e more c_2 implies less c_1, hence the following conversely proportional relation for any two concepts i, j:

$$(iP_-j) \Longrightarrow (c_i \nearrow) \wedge (c_j \searrow) \tag{2}$$

For instance, (1) more mature will be the H_2 technologies (c_7), more the cars will be present in the market (c_6); (2) more will be the safety in H_2 cars (c_4), less will be the risk of H_2 explosion (c_5).

The final objectives hierarchy created by applying the previous theoretical and practical rules ($\mathbf{R_1}$, $\mathbf{R_2}$, $\mathbf{R_3}$, $\mathbf{R_4}$) on example 6 map, w.r.t the matrix connecting items, consist of a 3-levels value tree of objectives: The first level starts with the main goal of improving the acceptance of H_2 systems. To reach this main objective, the second level objectives are to maximise safety and minimise costs. The third level is achieved by three objectives: first the objective of maximising safety is assumed to be reached by minimising risk of explosion and maximising control of systems, second the objective of minimising costs is reached by maximising the number of H_2 powered cars present in the market, etc. Practically this consists in transforming Figure 6 to Figure 7.

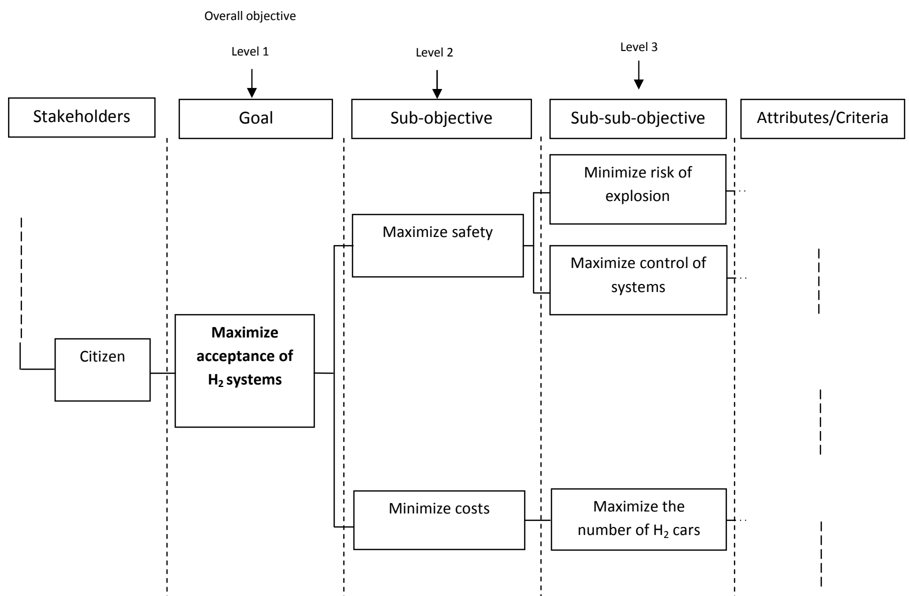

Figure 7: Partial value tree on H_2 powered cars.

5. Real-world case based on hydrogen technology assessment

5.1. Example description and decision problem

This study was carried out in France within the context of the AIDHY (Decision support for the identification and support to societal changes brought about by new technologies of Hydrogen. A multidisciplinary project initiated by the French National Research Agency (ANR)) project aiming at (1) Understanding the factors of the social acceptability of hydrogen technologies as an energy carrier, and (2) Providing tools to integrate these factors in development scenarios of these technologies (see [34]). The depletion of fossil fuels, the environmental concerns and the rise of renewable energy, provide an overview of the current energy environment. The analysis of such information allows the formulation of concrete decision problems. Hydrogen is an energy carrier, i.e is a form of energy transposable, to be used in a place different from where it is produced. It's a way to store energy for later use. An energy carrier does not exist in nature but is produced using different primary energy sources. For different uses, hydrogen needs to be produced, stored, and converted into useful energy in technical systems as shown in Figure 8 representing the hydrogen chain. There are several technologies for each of the activities in this chain, each with advantages and disadvantages. In addition, the introduction of these new technologies in the circuit of mass consumption could meet the opposition or even rejection by the general public. Thus, in such condition of multiple alternatives with different consequences, decisions must be taken in order to establish which technologies or group of technologies should be promoted w.r.t to social acceptability. This constitutes an assessment problem, an issue that arises in energy planning.

This particular assessment problem is characterised by a high level complexity, regarding both the multiple stakeholders and the social dimensions to be considered. The complexity of the problem suggests the need to adopt an integrated methodology to assist the hydrogen social acceptability process, providing a better understanding of it without leaving important features unattended. For this purpose, a problem structuring approach was adopted. Keeping in mind that at this stage we are interested in understanding how different types of stakeholders could react with respect to different scenarios of H_2 technologies deployment, we identified three classes of stakeholders: political decision makers, hydrogen industry actors, and the general public (citizens). In this paper, we focus only on the structure of the objectives of the public. Initially, cognitive maps relating to groups of individuals who are representative of different sensitivities of the public in relation to energy issues, were co-constructed. Then we implemented the approach described in section 4 to convert these cognitive maps to a value tree of the objectives of the public.

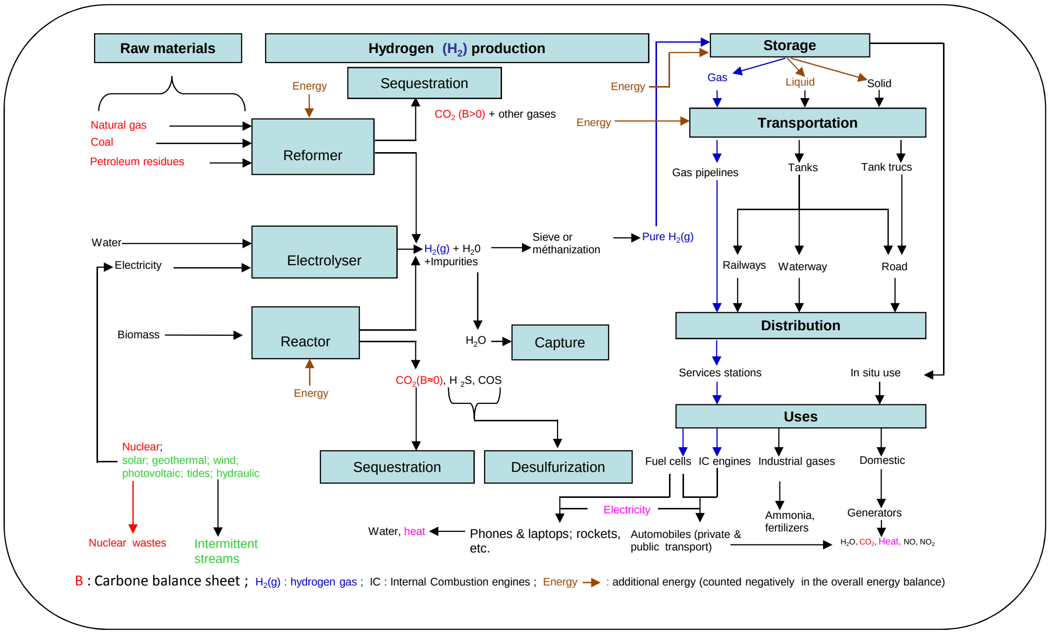

Figure 8: Integrated hydrogen chain

5.2. Cognitive maps

At an early stage of the decision aiding process, we wanted to share the same understanding of the problem, given the multidisciplinary nature of the project. To this end, through several rounds of discussions with participants including hydrogen experts, in addition to a literature review, we constructed a graphic encompassing its key points (see Figure 8). This first study structured the knowledge about hydrogen, and then submit it to the validation of the expert group in order to focus our work on a shared vision of the problem of hydrogen. This framework is a result of our problem structuring, combining group interactions with feedback from other pilot projects in the same field. At this stage of the process, only technical considerations were taken into account. The integration of the social acceptability in the process really began with the construction of the cognitive maps [14].

Three focus groups were conducted by the second author in order to gather informations on the perception of hydrogen by different interest groups. The first author participated as an observer in order to ensure that the need to bring out useful information for an implementation in a valuation model was taken into account within the discussions. Ahead of focus groups, we have identified specific needs for a multi-criteria analysis perspective such as (i) setting goals and establishing priorities and trade-offs between the competitive ones, and (ii) setting criteria and alternatives. In the implementation of the focus groups, three citizen panels representing the general public were selected on the basis of their affinity with the problem of energy (for more details about these specific focus groups see [14]):

1. *Frequent users of public transport*
2. *Frequent users of personal car*
3. *Users of green technologies of power generation*

The activity of cognitive mapping that follows a particular protocol, allowed the facilitator to build the following cognitive maps of the previous categories (Figures 9, 10, 11).

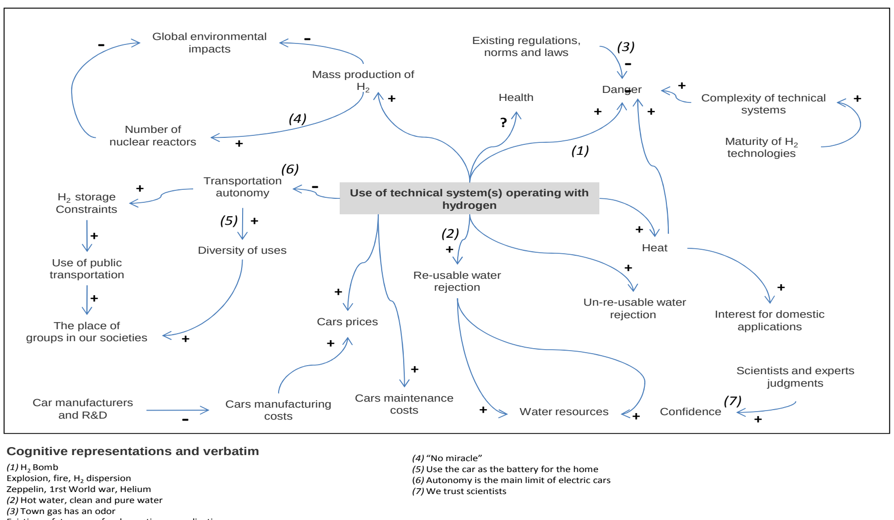

Figure 9: Collective cognitive map of frequent users of public transport.

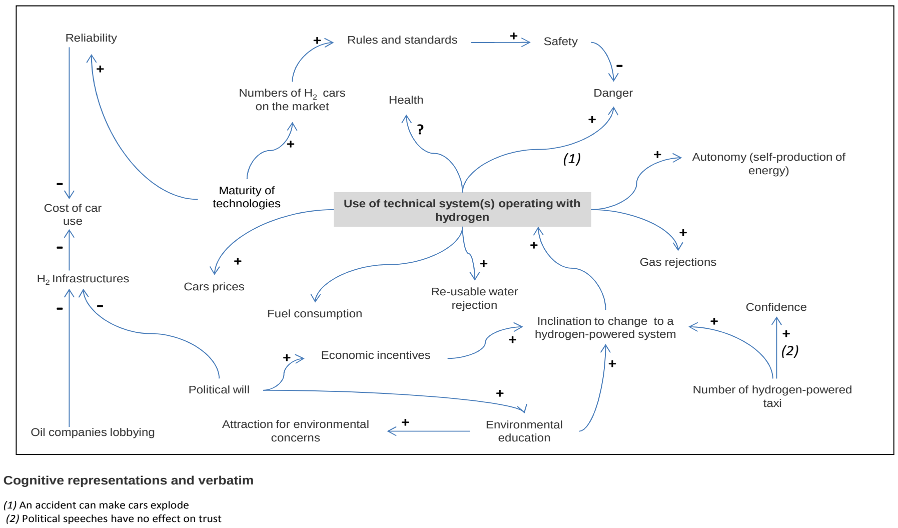

Figure 10: Collective cognitive map of frequent users of personal car.

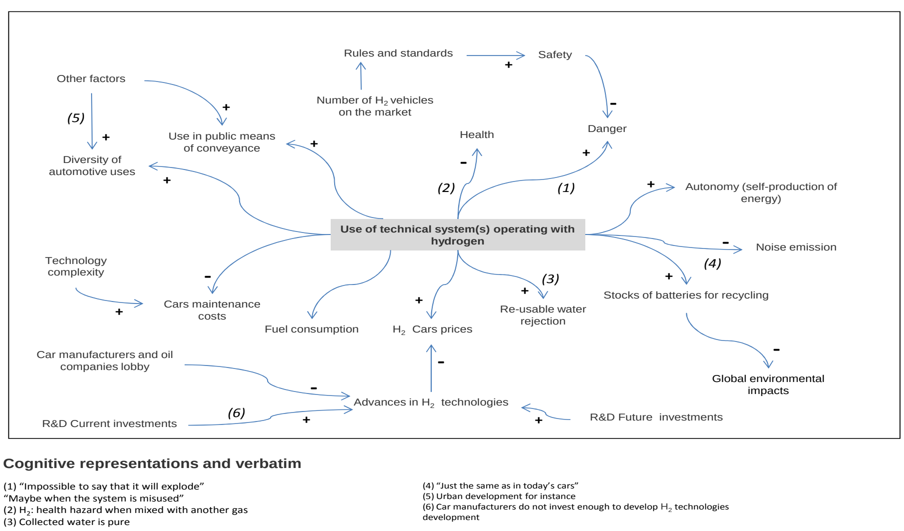

Figure 11: Collective cognitive map of users of green technology of power generation.

5.3. Value tree of objectives

The value tree representing the objectives of the public resulting from the application of the graphical conversion described in section 4 is displayed in

Fig. 12. A principal characteristic of these value trees of objectives is that they branch with increasing specificity from top to bottom. This characteristic is illustrated by the fact that the lowest level (third level) contains the greatest detail. The level selected to be used as evaluation criteria in a decision aiding process needs to be sufficiently detailed in order to allow quantification and measurement, but not that detailed to confuse analysis by drowning decision makers in a plethora of information, deviating them from the main goal of the process. The process of shaping the value tree into an operable form is an important aspect in developing a multi-criteria based decision-aiding process, where an appropriate balance between being too general and too detailed needs to be found. Therefore, some of the detailed objectives in cognitive maps shown in Fig. 9, 10, 11 were eliminated and categorised in a different way, so as to have more defining objectives in the value tree, inclusive of details that were removed.

Using the theoretical foundations and the practical tips described in section 4, and following the steps in Table 2, we obtained the Meta-value tree in Fig. 12 where the concerns about the acceptability is distributed following three generic categories of actors of the public.

Step N°	**Description of the step**
1	Interviews between the facilitator/analyst and several representatives of stakeholder groups
2	Structuring of values into a hierarchical order by the facilitator/analyst
3	Feedback of the value tree to stakeholder groups for comments or modifications
4	Iteration of process until each stakeholder group is satisfied with the final output
5	Combination of all stakeholder groups specific value trees into a single “meta-tree”
6	Validation of the meta-tree by all participant groups (with the option of deleting criteria they dislike)

Table 2: Stages of interactive elicitation of value tree of objectives

The three generic categories of actors of the public we mentioned above are:

1. Users of H_2 technical systems
2. Neighbours of H_2 technical systems

3. Citizens in a broad political sense

The objectives of these categories of actors are detailed in a meta-tree which is a tree constructed from the trees of each category of stakeholders groups by merging different trees. Only the resulting meta-tree is given here (Figure 12). The first level of the meta-tree is a separator which divide different stakeholders into the three generic categories of actors above. The following levels represent objectives, sub-objectives, etc.

Acceptability of H_2 technologies by general public

- Users
  - Individual vehicles
    - Reduce cost
      - Reduce purchase cost
      - Reduce utilization cost
      - Reduce maintenance cost
    - Improve services
      - Increase usage autonomy
      - Improve after-sales service and maintenance
    - Improve usage comfort
    - Improve security of utilization
  - Public means of conveyance
    - Reduce utilization cost
    - Improve usage comfort
    - Improve security on board
  - Mobile devices
    - Improve fuel cells security
    - Improve fuel cells friability
    - Reduce purchase cost
    - Improve fuel cells autonomy
  - Domestic stationary usage
    - Improve security of H2 stationary domestic systems
    - Reduce purchase cost of H2 stationary domestic systems
    - Improve H2 stationary domestic systems autonomy
- Hydrogen pathway neighbouring
  - Production
    - Limit nuisance
    - Improve security
  - Storage
    - Improve security
  - Transport
    - Limit nuisance
    - Improve local environment
  - Utilization
    - Improve security
- Citizen
  - Global environmental worries
    - Limit climatic changes
    - Reduce nuclear waste
  - Knowledge of H2 technologies
    - Increase public knowledge of H2 technologies
  - Confidence in H2 technologies holders
    - European norms
    - National norms
    - Manufacturers

Figure 12: Value tree of objectives for the general public

The overall hierarchy of the value tree we obtain consists of four levels, starting with the main goal: capturing the social acceptability of H_2 technologies. The next (second) level is about to achieve this main objective, by minimising economics impacts, maximising safety, minimising environmental impacts, maximising services, and maximising confidence. In the third level, the objective of minimising economics impacts is supposed to be reached by minimising purchase cost, minimising utilisation cost and minimising maintenance cost. Maximising safety is achieved by maximising security and maximising reliability. Minimising environmental impacts is obtained by minimising nuisance, minimising climatic change, minimising batteries for recycling and minimising nuclear waste. Maximising services is reached by maximising usage autonomy, maximising the number of service stations, and maximising after-sales service and maintenance service. Maximising confidence is achieved by maximising information sources, maximising confidence in National and European norms, and maximising confidence in manufacturers of H_2 systems. This description is obtained from Tables 3 and 4. Then the criteria are derived from the lowest level objectives as shown in Table 5.

1^{rst} level objectives	2^{nd} level objectives
Social acceptability	Economic aspects
	Safety aspects
	Environmental impacts
	Supply security
	Services
	Confidence

Table 3: objectives hierarchy

Tables 3, 4 and 5 are a way of presenting the information in Figure 12 so that they can be used in a valuation model, but not only. Indeed, all sub-objectives of the hierarchy of objectives are not directly measurable. Table 4 therefore allows to solve this problem by associating each low-level objective to an attribute or criterion. This is justified by the presence of Table 5 which is logically accompanied by Tables 3 and 4 to ensure a consistent presentation of the hierarchical decomposition.

3^{th} level objectives	4^{th} level objectives	Direction
Economic aspects	Purchase cost	Min.
	Utilisation cost	Min.
	Maintenance cost	Min.
Safety aspects	Security	Max.
	Reliability	Max.
Environmental impacts	Climatic change	Min.
	Nuclear waste	Min.
	Nuisances	Min.
Supply security	Energy independence	Max.
	Autonomy	Max.
Services	Service stations	Max.
	Maintenance services	Max.
Confidence	Information sources	Max.
	Confidence in norms	Max.
	Confidence in H_2 systems manufacturers	Max.

Table 4: objectives hierarchy (continued)

4^{th} level objectives	Criteria	Direction
Purchase cost	Purchase cost	Min.
Utilisation cost	Utilisation cost	Min.
Maintenance cost	Maintenance cost	Min.
Security	Perceived safety	Max.
Reliability	Operating time without failure	Max.
Climatic change	CO_2 emissions	Min.
Nuclear waste	Additional nuclear reactors	Min.
Nuisances	Sonore emissions	Min.
Energy independence	Diversity of sources in energy mix	Max.
Autonomy	Distance covered	Max.
Service stations	Availability of service stations	Max.
Maintenance services	Availability of maintenance services	Max.
Information sources	Number of information sources	Max.
Confidence in norms	Degree of confidence in norms	Max.
Confidence in manufacturers of H_2 systems	Degree of confidence in manufacturers	Max.

Table 5: Criteria definition from objectives hierarchy (concluded)

6. Concluding remarks

In this paper, we discussed how evidence from cognitive mapping analysis can be translated into multiple criteria decision analysis by the mean of value trees of stakeholders objectives. Our claim is that this tools integration can be done with some theoretical and practical manipulations based on some rules, exploiting and taking advantage of appropriate graphical representation of the issue w.r.t the problem formulation.

More specifically, the work performed aimed at developing a methodological framework to inform the integration of CM into MCDA in the context of assessing hydrogen technology scenarios w.r.t their social acceptability. As this decision situation consists of a broad range of stakeholders with possibly conflicting and unstructured views, it appears difficult to make a "good" or "rational" decision in such a "social mess". In such "ill-defined" decision context, it was crucial that the related decision problem is structured in order to build consensus among stakeholders' objectives. However, structuring this problem needs to take specifically into account how to construct such a consensus and this is the reason for which CM comes into play. A small example combining CM and value tree of objectives (VTO) has been used to illustrate our approach, paying special attention to theoretical and practical standards we propose to operate the transfer from one map to another. Then this approach has been applied in a real world case dealing with the problem of the social acceptability of hydrogen technologies scenarios. The obtained results of this project showed that, in spite of some limitations, the framework has been able to structure the decision problems, leading to an operational and consensual evaluation model [34]. The developed methodology is quite different from other approaches documented in the literature where one can find either direct assessment of options with fuzzy cognitive maps (FCM) or the generation of VTO by a wish list, but not the combined use of both techniques. It encompass both paradigms in a framework that is able to accommodate a decision context with multiple stakeholders and multiples possibly conflicting objectives.

The suggestion for further developments concerns designing further experiments to test the impact of our two-stage methodology (cognitive mapping and value tree) on the consistency and effectiveness of the family of criteria obtained in the sense of Bouyssou et al. (see [8], [9]) w.r.t criteria axioms [34]. Whereupon, framing and formalising an algorithmic procedure of our integrated methodology is to be investigated.

References

[1] L. Adelman, P.J. Sticha, and M.L. Donnell. An Experimental Investigation of the Relative Effectiveness of two Techniques for Structuring Multiattribute Hierarchies. *Organizational Behavior and Human Decision Processes*, 37:188–196, 1986.

[2] R. Axelrod. *Structure of Decision: The Cognitive Maps of Political Elites*. Princeton University, 1st edition, 1976.

[3] V. Belton, F. Ackermann, and I. Shepherd. Integrated support from problem structuring through to alternative evaluation using COPE and VISA. *Journal of Multi-Criteria Decision Analysis*, 6:115–130, 1997.

[4] V. Belton and T. Stewart. *Multiple Criteria Decision Analysis: An integrated approach*. Kluwer Academic Publishers, 2001.

[5] K. Borcheding and D. Von Winterfeldt. The Effect of Varying Value Trees on Multiattribute Evaluations. *Acta Psychologica*, 68:153–170, 1988.

[6] M. Bougon, K. E. Weick, and D. Binkhorst. Cognition in organizations: an analysis of the Utrecht Jazz Orchestra. *Administrative Science Quarterly*, 22(4):606–639, 1977.

[7] M.G Bougon. Uncovering Cognitive Maps: The Self-Q Technique. In G. Morgan, editor, *Beyond Method: Strategies for Social Research*, pages 173–188. CA: Sage, Beverly Hills, 1983.

[8] D. Bouyssou, Th. Marchant, M. Pirlot, P. Perny, A. Tsoukiàs, and P. Vincke. *Evaluation and Decision Models: A Critical Perspective*. Kluwer Academic Publishers, Dordrecht, 2000.

[9] D. Bouyssou, Th. Marchant, M. Pirlot, A. Tsoukiàs, and P. Vincke. *Evaluation and Decision Models with Multiple Criteria: Stepping stones for the analyst*. Springer, Berlin, 2006.

[10] P.B. Checkland. *Systems Thinking, Systems Practice*. Wiley, Chichester, 1st edition, 1981.

[11] O. Coban and G. Secme. Prediction of socio-economical consequences of privatization at the firm level with fuzzy cognitive mapping. *Information Sciences*, 169:131–154, 2005.

[12] P. Cossette. *Cartes cognitives et organisation*. Les Editions de l'ADREG, 2ème edition, 2003.

[13] S. Damart. Cognitive Mapping Approach to Organizing the Participation of Multiple Actors in Problem Structuring Process. *Group Decision and Negociation*, 19(5):505–526, 2010.

[14] S. Damart. Focus groups de l'acceptabilité de l'hydrogène: rapport de synthèse phase qualitative. Technical report, M-Lab, Paris, 2011.

[15] N. Deo. *Graph theory with applications to engineering and computer science*. Prentice Hall, 1974.

[16] J. Dewey. *How we think*. Dover Publications Inc, 1998.

[17] R. Diestel. *Graph theory*. Springer Verlag, Berlin, 2010.

[18] C. Eden. Cognitive mapping: a review. *European Journal of Operational Research*, 36:1–13, 1988.

[19] C. Eden and F. Ackermann. SODA-journey making and mapping in practice. In J. Rosenhead and J. Mingers, editors, *Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict*, pages 43–60. Wiley, London, 2001.

[20] C. Eden and F. Ackermann. Cognitive mapping expert views for policy analysis in the public sector. *European Journal of Operational Research*, 152:615–630, 2004.

[21] C.M. Fiol and A.S. Huff. Maps for managers: where are we? where do we go from here? *Journal of Management Studies*, 29(3):267–285, 1992.

[22] J. Friend and A. Hickling. *Planning under Pressure: the Strategic Choice Approach*. Butterworth-Heinemann Ltd, 3rd edition, 2004.

[23] M.L. Galves. structuring decision situations: a brief overview. In J.-P. Barthélemy and P Lenca, editors, *Advances in Multicriteria Decision Aid*, pages 32–40. GET/ENST Bretagne, 2005.

[24] M. Gondran and M. Minoux. *Graphes et algorithmes*. Eyrolles, 2ème edition, 1985.

[25] R. E. Horn. Knowledge Mapping for Complex Social Messes. A presentation to the "Foundations in the Knowledge Economy" at the David and Lucile Packard Foundation. Available on http://www.stanford.edu/ rhorn/a/recent/spchKnwldgPACKARD.pdf (accessed October 16, 2011), 2001.

[26] M. Jones, C. Hope, and R. Hughes. A Multi-Attribute Value Model for the Study of UK Energy Policy. *Journal of Operational Research Society*, 41(10):919–929, 1990.

[27] R. Keeney and H. Raiffa. *Decision with Multiple Objectives:Preferences and Value Tradeoffs*. Wiley, New York, 1976.

[28] R.L. Keeney. *Value Focused Thinking: A Path to Creative Decisionmaking*. MA: Harvard University Press, 1992.

[29] G.A. Kelly. The psychology of personal constructs. In J. Rosenhead and J. Mingers, editors, *Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict*, pages 43–60. Wiley, London, 2001.

[30] J. M. Komocar. *Participant cause maps of a work setting: an approach to cognition and behavior in organizations*. PhD thesis, Urbana IL: University of Illinois at Urbana-Champaign, Illinois, 1985.

[31] B. Kosko. Fuzzy Cognitive Maps. *International Journal of Man-Machine studies*, 24:65–75, 1986.

[32] B. Kosko. *Neural Networks and Fuzzy Systems: A dynamic system approach to machine intelligence*. Prentice Hall, New Jersey, 1991.

[33] B. Kosko. *Fuzzy Engineering*. Prentice Hall, New Jersey, 1996.

[34] A. Kpoumié. *Model for structuring and evaluating hydrogen technologies scenarios in terms of social acceptability*. PhD thesis, Université Paris Dauphine, LAMSADE, France, 2012. In progress.

[35] K.-Y. Kwahk and Y.-G. Kim. Supporting business process redesign using cognitive maps. *Decision Support systems*, 25:155–178, 1999.

[36] S.K. Langfield. Exploring the need for a shared cognitive map. *Journal of Management Studies*, 29(3):349–368, 1992.

[37] S. Lee, J.F. Courtney, and R.M. O'Keefe. A system for organizational learning using cognitive maps. *Omega*, 20(1):23–36, 1992.

[38] G. De Marchi, G. Lucertini, and A. Tsoukiàs. From Evidence - Based Policy - Making to Policy Analytics. *Cahier du LAMSADE*, 319:1–32, 2012.

[39] G. Montibeller, F. Ackermann, V. Belton, and L. Ensslin. Reasoning Maps for Decision Aiding: an integrated approach for problem structuring and multi-criteria evaluation. *Journal of the Operational Research Society*, 59:575–589, 2008.

[40] G. Montibeller, V. Belton, and M.V.A. Lima. Supporting Factoring Transactions in Brazil using Reasoning Maps: a language-based DSS for evaluating accounts receivable. *Decision Support Systems*, 42(4):2085–2092, 2007.

[41] F. Montignac. An MCDA approach for evaluating hydrogen storage systems for futur vehicles. In 2^{nd} *Decision Deck Workshop*, pages 1–2. Université Paris Dauphine, 2007.

[42] F. Montignac, V. Mousseau, M.A. Aloulou, D. Bouyssou, B. Rousval, and S. Damart. An MCDA approach for evaluating hydrogen storage systems for future vehicles. In Raymond Bisdorff, Luis Dias, Vincent Mousseau, and Marc Pirlot, editors, *Evaluation and decision model: real case studies*. Springer, 2012. to appear.

[43] G. Munda. Social Multi-Criteria Evaluation: Methodological Foundations and Operational Consequences. *European Journal of Operational Research*, 158:662–677, 2004.

[44] J. Mustajoki and R.P. Hämäläinen. Web-HIPRE: Global Decision Support by Value Tree and AHP Analysis. *INFOR*, 30(3):208–220, 2000.

[45] A. Phdungslip and T. Wuttipornpun. Decision Support for the Selection of Electric Power Plants Generated from Renewable Sources. *World Academy of Sciences*, 75(6):143–168, 2011.

[46] M. Pöyhönen, H. Vrolijk, and R.P. Hämäläinen. Behavioral and Procedural Consequences of Structural Variation in Value Trees. *European Journal of Operational Research*, 134:216–227, 2001.

[47] H. Raiffa. *Decision Analysis: Introductory Lectures on Choice under Uncertainty*. Mcgraw-Hill College, 1968.

[48] J. Rosenhead and J. Mingers. *Rational Analysis for a Problematic World Revisited:Problem Structuring Methods for Complexity, Uncertainty and Conflict*. Wiley, Chichester, 2001.

[49] T.L. Saaty. *The Analytic Hierarchy Process*. McGraw-Hill, New York, 1980.

[50] S.O. Sahin, F. Ulengin, and B. Ulengin. Cognitive mapping expert views for policy analysis in the public sector. *European Journal of Operational Research*, 152:615–630, 2004.

[51] A. Salo and R.P. Hämäläinen. On the Measurement of Preferences in the Analytic Hierarchy Process. *Journal of Multi-criteria Decision Analysis*, 6:309–319, 1997.

[52] H.A. Simon. Rational choice and the structure of the environment. *Psychological Review*, 63(2):129–152, 1956.

[53] P. Thery, P. Raphaele, and P. Zarate. Energy planning: a multi-level and multicriteria decision making structure proposal. *European Journal of Operations Research*, 17(3):265–274, 2009.

[54] E.C. Tolman. Cognitive maps in rats and men. *Psychological Review*, 55:189–208, 1948.

[55] A. Tsoukiàs. On the concept of decision aiding process: an operational perspective. *Annals of Operations Research*, 154(1):3–27, 2007.

[56] K.E. Weick and M. Bougon. Organizations as cognitive maps: charting ways to success and failure. In Sims H.P. and Gioia D.A, editors, *The Thinking Organization: dynamics of organizational social cognition*, pages 102–135. Jossey-Bass, 1986.

[57] R. Wilson. *Introduction to Graph Theory*. Addison Wesley, New-York, 1996.