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On the Perspective of using Multiple Agent Multi Criteria Decision Making for determining a fair Value of Carbon Emissions in Transport Planning

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Abstract

The valuation of carbon emissions is a relevant issue in transport planning. The Impact Assessment Models (IAMs) are adopted to obtain a fair price, but they provide a range of six orders of magnitude. We propose an integrative approach, based on the Multiple Agent Multi Criteria Decision Making (MAMCDM). The development of this methodology reveals some interesting potential: the coexistence of a technical approach (provided by IAMs) and a sociological analysis (deriving from MAMCDM) seems to grant a less conflicting and shared value of CO_2 emissions, thus contributing to reduce the uncertainties and to limit the range of values.

Peer-review under responsibility of CIT 2014.

Keywords: Transport Policy; Carbon Dioxide Estimation; Multi Agent Multi Criteria Decision Making, Impact Assessment Models, Damage Cost

1. Introduction

Let us imagine that a planner is involved in the relevant issue of determining the CO_2 value for a given transport mode or infrastructural system. Let us concede that he/she has a thorough knowledge of the scientific literature and is aware of the scientific uncertainties related to this computation (Stanton et al., 2009). This planner should know that this issue has to be solved with a two-step process.

The first step is the quantification of CO_2 emissions. This can be achieved by drafting a balance or a simulation method (Nocera and Cavallaro, 2011; Nocera et al., 2012; Cavallaro et al., 2013). The second step of the process is the monetization of such emissions. Monetization is the process of valuating costs and benefits that are not directly expressed as monetary expenditures and revenues onto the same monetary scale, by multiplying the quantity by a unitary price. Monetization of CO_2 emissions is a relevant criticism in the scientific and political debate, which is far from a fair solution (Nocera and Cavallaro, 2014a; 2014b). Several alternative methods have been developed, according to the temporal horizon and the type of emissions considered. They can be roughly distinguished between "market-based" and "academic" methods (Nocera and Tonin, 2014).

"Market-based" methods include the Carbon Tax and Carbon Trading Costs. The Carbon Trading Cost, derived from the EU Emissions Trading System (EU, 2012a) is based on the 'Cap-and-Trade' law (EU, 2012b). The maximum amount of CO_2 that may be emitted without paying a fee is limited to a given value (i.e., "cap"). Within this cap, companies receive emission allowances that they can sell to or buy from one another (i.e., "trade"). The Carbon Tax is applied by every nation, and is based on the carbon

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content of fuels or on the estimated CO_2 emitted in the fuel combustion process (Santos et al., 2010). The Carbon Tax is normally the preferred method for the transport sector (Avi-Yonah et al., 2008) because it is easier to enforce and less influenced by market fluctuations; the Cap-and-Trade system, on the other hand, works well with stable sectors, such as industry and electrical power plants, where quantifying emissions is relatively easy.

"Academic" methods consist mainly of "Avoidance" and "Damage" Costs. They are based on the quantification of the economic impacts deriving from the environmental consequences of CO_2 emissions. The Avoidance Costs (also known as "Mitigation" or "Control" Costs) quantify the funds required to reduce CO_2 emissions and to lower their atmospheric value. Avoidance Costs are based on a cost-effectiveness analysis that expresses the optimum price to achieve a given target. From an economic perspective, it is a method that determines the least cost option to achieve a required reduction level of CO_2 emissions. Emissions are at their optimum level when the incremental social costs of additional abatement (i.e., reducing emissions by one tonne) are equal to the additional social benefits of avoided damage.

The Damage Cost method assesses the future physical impacts of climate change and links them to consequences on a society and its economy. This method is based on a Cost Benefit Analysis (CBA), which determines the optimal policies to adopt on the basis of the environmental, social and economic consequences expected, and then evaluates whether the benefits are expected to exceed the costs.

There is no absolute method for calculating a reliable unitary economic value of CO_2. However, for long-term analyses, the use of the Damage Cost is preferred, because it is neither related to political decisions or scenarios (like the Carbon Tax or Avoidance Cost) or to market fluctuation (like carbon trade). Furthermore, this method is adopted in other environmental analyses of external costs, thus making the results comparable with other fields. Nevertheless, by adopting the Damage Cost method, the range provided by the literature is enormous, which spans six orders of magnitude (Tol, 2008; Nocera and Cavallaro, 2012).

The question that a planner must address is how to obtain a fair value of such emissions, if the range of the unitary values is so vast. This paper tries to solve the problem by proposing the MAMCDM as a possible solution. The paper is structured as follows: in section two, a different theoretical approach is presented, based on a sociological method. Sections three and four investigate this method in greater detail, describing respectively the MAMCDM and its possible adoption in the valuation of CO_2 emissions. Some conclusions and future proposals end the contribution, showing how MAMCDM could be used to support transport decision-making and the development of correct policies in the valuation of carbon dioxide.

2. From a "hard science" approach to a sociological perspective

As stated in the introduction, the Damage Cost is the preferable method for long-term analysis of CO_2 values. The Damage Cost can be obtained in different ways: it is possible to multiply estimates of the ''physical effects'' of climate change with estimates of their price (Fankhauser, 1994, 1995; Nordhaus 2008; Nocera and Cavallaro, 2014; Tol, 2002a, 2002b). Alternatively, Bosello et al. (2012) use similar estimates of the physical impacts but compute the general equilibrium effects on welfare. Finally, other methods may consist of using observed variations (across space) in prices and expenditures to discern the effect of climate (Nordhaus, 2006), or in drafting self-reported well-being (Maddison and Rehdanz, 2011).

The Impact Assessment Models (IAMs) are the technique most adopted to valuate the Damage Costs deriving from CO_2 emissions (Stanton et al., 2009). IAMs link the unitary value with their physical changes caused by CO_2 emissions, thus establishing a direct connection between the physical changes caused by the emissions and their economic consequences.

Nonetheless, the range of values included is between -\$10.00 /tC and \$7,243.73/tC (Nocera and Tonin, 2014). To limit this vast range, a meta-analysis of the values proposed by literature can be made (Nocera et al., 2014). The main descriptive statistics of this meta-analysis, based on 699 observations, reveal that the mean value is 276.49 \$/tC, the median 85\$/tC, and the standard deviation 668.78\$/tC. This kind of technical analyses can be relevant to determine the main statistics deriving from the IAMs. They also contribute in reducing the uncertainties of the carbon price. However, these approaches do not consider the dynamic interactions between the different positions of the actors involved in the process of determining the final price.

To understand this point, a different perspective is introduced. This vision is mostly selected in the social sciences and is based on the social construction of acceptance. If we reformulate the process previously described as adopting a sociological perspective (Pinch and Bijker, 1984), what happens by adopting the IAMs is that differing explanations are sought for what is taken to be a scientific truth or falsehood (approach "A" in figure 1). In the case of CO_2 emissions, this would mean to reach a univocal relationship between global warming, climate changes, discount rates and all the parameters previously listed. There is a huge debate about these aspects (Tol, 2013), and a final agreement is very difficult to be found due to the presence of several uncertainties (Clarkson and Deyes, 2002). Unavoidably, this has led to the vast range of values previously recalled. A polarization of positions and the adoption of a DEAD approach (acronym of Decision, Education, Announcement and Defense: Hartz-Karp, 2007) are the most common consequences. In such cases, the risk is the adoption of a proposal, which coincides with the point of view of the authorities or stakeholders that have greater interests but does not consider other relevant instances. This position includes the problems related to the lack of participation; its consequences are visible in many transport fields, but mostly when the realization of new infrastructures and the introduction of new transport policies are considered (Caruso, 2010; Cavallaro and Maino, 2014).

On the other hand, an alternative approach ("B" in figure 1) suggests that all knowledge and knowledge-claims be treated as being socially constructed. This implies the switch from a pure technical analysis to a more comprehensive vision. This method is mostly used in the management of social conflicts, where the final effect is unknown, stances are different, and more viewpoints are considered. CO_2 emission price can be included in this group: here, the environmental and economic effects of emissions are not univocally determined (Watkiss et al., 2005) and several conflicting positions can be found (Stern, 2007). Nevertheless, to our knowledge, this sociological approach has yet to have been used in the valuation of CO_2 emissions. It could be based on the *frame theory,* as proposed by Schön and Rein (1994). A frame represents the actors' values and mental conception of the world. It allows for the understanding of the different actors' background and the reasons behind their specific positions. As far as CO_2 is concerned, this can be produced by analyzing the vast number of variables that must be chosen by the modelers in IAMs to determine a price, as better clarified in the next section. This first phase allows determining the different positions as well as the controversies of the actors involved in the process. The following phase is the construction of a shared methodology through a process of reframing: this implies a redefinition of the problems starting from a new approach, combined in a dynamic way with the aspects that were previously only partially considered or omitted. Reframing is a complex conceptual operation, which, operatively, can be produced by using a MAMCDM. At the end of this phase, a more shared vision about the problems may be obtained, based not only on the scientific approach, but also on the social acceptance of the method and its results: an Announce, Discuss, Decide (ADD) approach. The two different approaches previously described are schematized in figure 1.

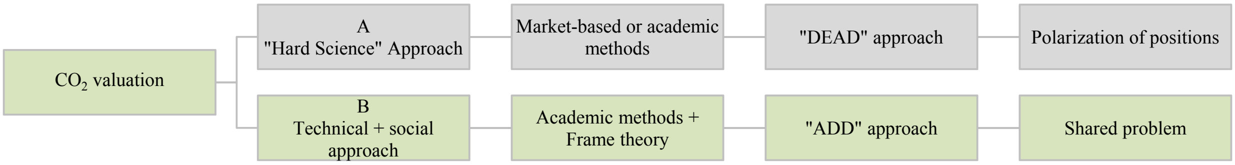

Figure 1. Two alternative approaches to evaluate CO_2 emissions

Since a relationship between MAMCDM and CO_2 is still lacking, the technical and social approach has not yet been adopted. The aim of the next two sections is to fill this gap, first by describing the MAMCDM (section 3) and then by linking it to the valuation of the transport emissions (section 4).

3. Multiple Agent Multi Criteria Decision Making (MAMCDM)

MAMCDM is a methodology that aims to support the process of decision, election, evaluation and negotiation of a suitable alternative when a number of agents (or groups of agents) are involved. This method is the combination of an evaluation method, the Multi Criteria Analysis (MCA, presented in section 3.1), with the Multi Agent System (MAS, described in section 3.2). Together, these two parts constitute an evaluation system that can take into account different criteria and different perspectives (section 3.3).

3.1 Multi Criteria Analysis

Multi Criteria methods are a type of decision analysis specifically designed for use in situations where it is important to transparently incorporate multiple considerations into a decision making process. MCA allows for the consideration of different performance criteria, especially those who cannot be reported in monetary terms. The main goal is to provide a clear, rational, documentable, comprehensive and defensible evaluation process. For this reason, MCA is a well-known method, widely adopted in different branches of transport, such as sustainable transport systems (Tzeng et al., 2005), decision support systems (Brand et al., 2002), time network equilibrium and system optimum problems (Yang and Huang, 2004), and urban network analyses (Cantarella and Vitetta, 2006).

In short, the method is based on seven steps (Sinha and Labi, 2007). First, the identification of the alternatives to be compared to has to be provided. This is achieved through the technical development of several alternative options, such as scenarios or projects.

Second, the performance criteria have to be chosen: this is a crucial point, because this decision determines the parameters on which the evaluation is based.

Third, the relative importance of such criteria has to be established. This process is called "weighting" and can be made through different methods, such as equal weighting, direct-weighting, regression-based observer-derived weighting, Delphi approach, gamble method, pairwise comparison and value swinging.

Fourth, a common unit of measurement has to be established, so that the comparison between criteria can be provided. This process is called "scaling" and can be obtained through a value function approach (if there is certainty in the evaluation) or through a utility function approach (if the evaluation is made under uncertainty). In cases of certainty, the scalar index of preferences is defined, which are the values of each level of a performance criterion (Keeney and Raiffa, 1976); in cases of uncertainty, a more general approach is adopted, which takes into account the risk preferences of the decision-maker as well.

Fifth, using the scale established during the last step, the levels (impacts) of each criterion for each alternative action are quantified.

Next, the performance criteria have to be amalgamated. This means that a unique value has been finally obtained for each scenario or project, which is the sum of all the scaled and weighted performance criteria.

This leads to the seventh and last phase, which is the choice of the most preferable solution. This choice can be expressed in mathematical terms, as seen in formula 1):

$$\mathrm{F(x)} = \{\mathrm{c}_1(x), \ldots, c_i(x), \ldots, c_k(x)\} \qquad 1)$$
$$x \in A = [\mathrm{a}_1, \ldots, \mathrm{a}_j, \ldots, \mathrm{a}_n]$$

where:

F(x) is the function of maximization or minimization, according to the objective of the evaluation;
c is a criterion taken into account in the analysis;
a is an alternative taken into account in the analysis;
A is the set of all the alternative solutions;
k is the number of criteria;
n is the number of alternatives.

When the decision about the best option is acted on, a sensitivity analysis can be carried out to verify which variations can effectively influence alternative performances (Cossu, 2005). Sensitivity analysis can be methodological, on criteria or on weights.

3.2 Multi Agent System

A Multi Agent System (MAS) models the interactions of agents (or groups of agents) in a given environment. MASs are strictly connected to the game theory, a mathematical approach that studies interactions between self-interested agents (Binmore, 1992). This kind of research has been developed in the framework of the computer sciences, decisions theory and operative research. The concept has been rapidly extended (Kubera et al., 2010), and agents are currently divided between *very simple agents* (passive agents or agent without goals, such as an apple), *active agents with simple goals* (such as wolves and sheep in a prey-predator model) and *very complex agents* (cognitive agents, indifferently human or virtual, which require many complex calculations).

A MAS is not an evaluation technique, such as MCA. If used alone, it does not help us to choose the best solution for a specific goal. Indeed, it is conceived to determine the relationships between actors and the environment, thus allowing to address several problems in combination with specific evaluation techniques (Ferber, 1999). Therefore, MAS can contribute to bring problem solving activity to a distributed dimension, rather than to a centralised approach, being that the former is well known as an effective approach (Davis and Smith, 1983). Furthermore, MAS gives the possibility to make artificial universes, which are small laboratories for the tests of theories about behaviours and the description of specific interaction mechanisms.

Considering its very wide conception, a MAS is constituted by an environment where agents interact. Five main characteristics can describe the environment (Norvig and Intelligence, 2002):

1) *Observability*. If the perception of an agent gives access to the complete state of the environment at each point in time, the environment is fully observable. This means that the agent can detect all relevant aspects to choose a specific action. Vice versa, an environment might be partially observable, if inaccurate information or unknown elements are given.
2) *Determinism*. If the future state of an environment is completely determined by the current state and the actions executed by an agent, an environment is deterministic; otherwise, it is stochastic.
3) *Episodicity or sequentiality*. In an episodic environment, the choice of actions in each event depends only on the latter and the next one does not depend on the actions taken previously in other events.
4) *Dynamism*. If the environment can change while an agent is deliberating, it is dynamic; otherwise, it is static. Static environments are easier to be dealt with, because the agent does not have to look at the world while deciding on an action. Dynamic environments, on the other hand, are continuously demanding a choice from the agent. If the environment does not change with the flow of time, but the agent's performance score does, the environment is called semidynamic.
5) *Discreteness***.** A partition does not allow for a continuity of space, time or perception. Discreteness can be applied to the state of the environment, to the way time is handled, and to the perceptions and actions of the agent.

Referring to the aim of the research presented in this paper, a group of decision makers can be seen as a MAS, interacting in a partially observable, stochastic, sequential, dynamic and continuous environment. The group decision activity could benefit from a decision support system (DSS), hence called Group Decision Support System (GDSS), a technology to support project collaboration through the enhancement of digital communication. These types of programs are used to support customized projects requiring group work, input to a group and various types of meeting protocols (Power, 2007). The wide use of software and technology suggested the research in GDSS progressively points out the importance of moderating the outcomes (Lim and Benbasat, 1992). A Negotiation Support System (NSS) needs a Decision Support System (DSS) for each negotiating party electronically linked to the other DSSs, allowing the negotiating groups to communicate electronically, creating the so-called Group Decision Negotiation Support System (GDNSS).

3.3 Multiple Agent Multi Criteria Decision Making

MAMCDM is a holistic approach that combines MCA and MAS. It aims to provide actors with a computer-based support system able to aid the decision process with a semi-structured decision task. In other terms, a choice-model that allows direct interaction with data and scenarios (Lim and Benbasat, 1997). The negotiation activity calls for a direct IT linkage between the actors and their support systems, thus forming a GDNSS. In a MAMCDM, the following elements have to be considered: a set D of d actors (s); a set A of n alternatives (a); a set C of k criteria (c); a mediator agent M. Operatively, MAMCDM runs on three main steps.

First, every actor s produces an individual $k \times n$ matrix with its evaluations and weights, w, on the alternatives a. Weighting is an important phase of MCA. It reflects the decision makers' preferences by the score they confer to each criterion k (Dodgson et al., 2009). The sum of the scores is unitary, and their repartition can determine an individual "pre-order rank", which is a list where the alternatives are sorted according to the preferences of every single decider. The specification "pre-order" suggests that this rank is still susceptible to changes from the following phases. Second, from those individual evaluations derives the group matrix **G** and a single ranked list of preferences (called "collective pre-order" rank). Third, the negotiation/group-decision process is carried out, where the mediator M participates actively. These three phases are described here in detail.

The first step consists of a MCA carried out by each actor, who assigns weights to the alternatives. Soon after, the pairwise comparison of the alternatives related to the specific criteria determines the preliminary preference order. Pairwise comparison (PC) is a consolidated technique. In decision making; a common problem are the missing judgments, especially when the number of alternative, k, is high. Indeed, PC strength lays in the several methods scholars developed to derive the priorities of the k alternatives even if a $k \times n$ matrix is incomplete (Fedrizzi and Giove, 2007). Preference levels can be measured on a scale going from 0 (no preference) to 1 (full preference). If the comparison between two alternatives results in a small deviation, there is either a weak preference or none at all, while clearer preferences are expected for broader deviations. Rather than pointing out a unique decision, this method helps actor to find the alternative that best suits their goals. The method provides a comprehensive and rational framework for structuring a decision problem, identifying and quantifying conflicts and synergies, clusters of actions, and highlighting the main alternatives and the structured reasoning behind this (Figueira et al., 2005). From the analysis of the flows, it is possible to understand many of these data.

A preference flow φ measures how an alternative, or group of alternatives, is preferred. Each alternative will result in two flows. The flow is called *positive* when it expresses how much an alternative a is preferred to the remaining $n - 1$ ones. It measures the strength of the alternative a and it is expressed by $\varphi_+(a) = (1/n - 1)\sum_{a1 \neq aj} \pi\left(a_1, a_j\right)$, where $\pi\left(a_1, a_j\right)$ is one arc of preference between two alternatives. The positive flow $\varphi_+(a)$ plus the negative one $\varphi_-(a) = (1/n - 1)\sum_{aj \neq a1} \pi\left(a_j, a_1\right)$, which measures how much the other $n - 1$ alternatives are preferred to the alternatives a (hence, its weakness), gives the net flow $\varphi(a) = \varphi_+(a) - \varphi_-(a)$ (VPsolutions, 2013). Flows can mainly be analysed with partial or complete ranking. Complete ranking presents an ordered list mathematically ordered by summing net and positive flows. Instead, partial ranking permits a comparison that enlightens conflicts and incomparabilities by keeping the flows separated. That is, an alternative could be preferable because of a particular feature, while could not score so well on another criteria. What we have here is an incomparability, or conflict.

The matrix in table 1 summarizes how an agent judges the alternatives according to the evaluation criteria. It provides their individual pre-order of the alternatives.

$$\begin{array}{cccccc}
 & c_1 & \cdots & c_i & \cdots & c_k \\
a_1 & \varphi_{11} & & \varphi_{1i} & & \varphi_{1k} \\
\vdots & & & & & \\
a_j & \varphi_{j1} & & \varphi_{ji} & & \varphi_{jk} \\
\vdots & & & & & \\
a_n & \varphi_{n1} & & \varphi_{ni} & & \varphi_{nk}
\end{array}$$

Table 1. The matrix with the criteria and the weights of each agent

where:

φ is the net flow that represents the evaluation of an agent concerning a specific criterion on an alternative;

j is the index attributed to alternative a: $A = \{a_j\}$, $j = 1 \ldots n$;

i is the index attributed to criteria c: $C = \{c_i\}$, $i = 1 \ldots k$.

Subsequently, every individual matrix can be converted into a net flow $\varphi_{si}(a)$, which represents the score that every actor s, according to the criterion i, attributes to the alternatives in the set A (Espinasse et al., 1997; formula 2):

$$\varphi_{si}(a) = \frac{1}{(n-1)\sum_{j=1}^{n}\left(P_{si}(a,x_j) - P_{si}(x_j,a)\right)} \qquad 2)$$

where:

φ, a, j, i are defined above;

s is the index attributed to actors: $D = \{d_s\}$, $s = 1 \ldots d$;
P is the preference function.

Every agent involved in the process has to produce their net flow $\varphi_{si}(a)$. Then, by summing all the $\varphi_{si}(a)$ for all the k criteria, the net flows $\varphi_s(a)$ for each agent s on an alternative a is calculated (formula 3).

$$\varphi_s(a) = \sum_{i=1}^{k} \varphi_{si}(a) \qquad 3)$$

The second step coincides with the creation of a matrix where the evaluation of the agents regarding the different alternatives are collected (table 2, columns D_1, D_s, D_d). Hence, given the net flows for each single actor on an alternative $\varphi_s(a)$, as described in formula 3), the group net flow φ_g for an action a can be calculated. It is the sum of individual net flows $\varphi_s(a)$ for every actor, with w_{si} representing the weight associated to every criterion i by the actor s, where the sum of the weights distributed through the k criteria by a decider s is 1:

$$\varphi_g(a) = \sum_{s=1}^{d} w_s \sum_{i=1}^{k} w_{si} \frac{1}{(n-1)\sum_{j=1}^{n} P_{si}(a,x_j) - P_{si}(x_{j,}a)} \qquad 4)$$

where:
φ, a, d, j, k, i, P are defined above;
g represents the group as a sum of the single actors;
w_{si} is the weight associated to each criterion i by the actor s.

The second phase ends by inserting into the matrix the values of the net group flows $\varphi_g(a)$ as calculated with formula 4). Now, the mediator is able to outline the collective pre-order of the listed alternatives. The net flow $\varphi_g(a)$ is represented in the last column *Group net flow(a)* of the matrix **G** (table 2).

Action	D_1	… D_s	… D_d	$Group\ net\ flow\ (a)$
a_1…	$\varphi_1(a_1)$	$\varphi_s(a_1)$	$\varphi_d(a_1)$	$\varphi_g(a_1)$
a_j…	$\varphi_1(a_i)$	$\varphi_s(a_i)$	$\varphi_d(a_i)$	$\varphi_g(a_i)$
a_n	$\varphi_1(a_n)$	$\varphi_s(a_n)$	$\varphi_d(a_n)$	$\varphi_g(a_n)$

*Table 2. The mediator matrix **G***

This process provides an ordered list of preferences, which is only partially satisfactory. The ordered list of group net flows $\varphi_g(a_1)$ rank final scores, overlooking contingent incomparabilities and conflicts emerging from the pairwise comparison of alternatives and criteria. If we recall the theoretical framework as expressed in section 2, $\varphi_g(a)$ allows for the enlightenment of the actors and their frames. The following phase consists of reframing the problem and in finding an agreement between the different instances. This can be made through the negotiation process and the introduction of a mediation's agent (third phase of the MAMCDM process).

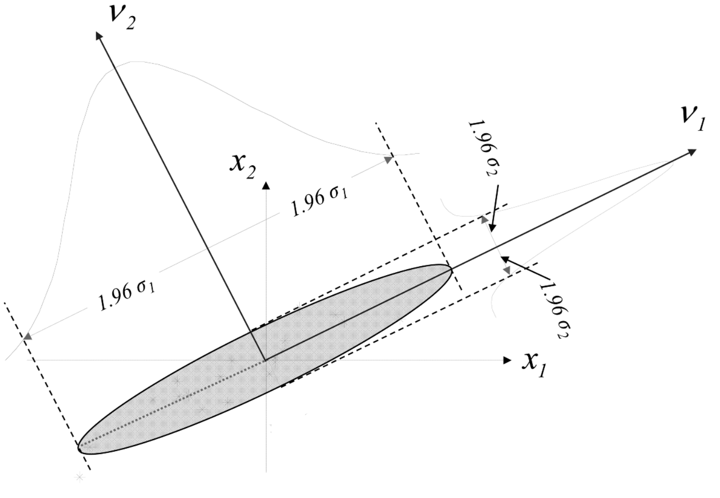

Figure 2. A geometrical representation as an orthogonal transformation of matrices flows. Source: Marsili-Libelli, 2014, modified

The most interesting feature of the process is its capability to enlighten potential conflicts, as outlined by the pairwise comparison. In order to perform this, a shift from the mathematical to a graphical representation of data can be useful. In this sense, MAMCDM allows for directly observing and evaluating any possible perspective: weights, actions, actors and criteria in any useful combination, to highlight the most substantial reasons for conflict. Data matrices can be expressed as coordinates in a multidimensional space, where each variable exists in one axis. To report the matrices to a bi- (or tri-) dimensional representation, a dimension-reduction technique called Principal Components Analysis (PCA) is required. PCA allows for defining orthogonal dimensions (as represented by the principal components v_1, v_2 in figure 2) in order to show data from the point of view which provides the maximum information from data distribution.

Furthermore, the process is helpful when data present a consistent autocorrelation, that is, the same information shared by two different variables. Even if the two/three dimensional representation of the problem implies a loss of information, arguably, the less important part of the data matrix, it is the maximum possible quantity of information from the k-dimensional representation. The first principal component is the one with the largest variance, and each following component has the highest variance under the constraint that it be orthogonal to the preceding components (Jolliffe, 2005). The PCA process works as follows: two dimensional representation of data is scattered on a reference plan (x_1, x_2). The axis v_1 and v_2 represent the widest data distribution for the given principal components, maximizing their variance. The change of the reference plan deriving from the rotation of the x_1 and x_2 to the v_1 and v_2 axis is a change of perspective. Its aim is to choose the observation point of view that shows the maximum amount of data, recalling the "reframing" theory here. Indeed, looking directly alongside the v_1 axis, the plan provides the maximum amount of information on the component v_1, considered within two standard deviations σ_2 from its mean (the v_1 axis). The same can be said for the component v_2.

Let us consider the net flows $\varphi_g(a)$ in formula 4): from this graphical data reduction it is already possible to identify the conflicting actors, which are represented by ajar vectors. Similarly, from formula 2), it is possible to evaluate the relative performance of an action on any criterion, according to the preference function defined by the decision-maker.

The spatial representation provides more intuitive information about actions, criteria and weights to be managed. Points in the Cartesian space represent actions: the closer the points are to each other, the more similar the actions are. A vector that joins a specific point with the center of the Cartesian plane represents a specific parameter (criterion, agent or alternative, at discretion), whose length indicates its relative discriminating power: the longer the axis, the more discriminating the parameter is. If the parameters under observation express similar preferences, then axes oriented in similar directions represent them; vice versa, two divergent vectors mean that there are opposing preferences.

The negotiation process consists of discussing with the agents the willingness to keep distance from their main preference. Spatially, a line that links the center of the axes and the coordinates (*x,y*) in the space that represent the preferred choice. By setting up a deterministic elasticity, expressed in percentage, every actor expresses the willingness to consider as acceptable another position included in this range. The point of agreement has to be fairly collocated according to the position of every agent and the equilibrium condition that better fits the actors. It could coincide either with a Nash Equilibrium condition, a solution that maximizes the payoff of each agent based on fairness, or with a Pareto Optimum, that is, the point of achievable joint evaluation from which no further joint gain is possible.

4. Use of MAMCDM in CO₂ valuation

So far, MAMCDM has been adopted in specific fields, mostly related to computer sciences, biology and robotics (Belz and Mertens, 1996; Bonetti et al., 2012). Other studies refer to the application towards environmental problems (Morais and de Almeida, 2007; Haralambopoulos and Polatidis, 2003). In the transport field, MAMCDM has been used for specific tasks mostly related with management operations. For example, Tzeng et al. (2005) pursued a MCA of alternative-fuel buses for public transportation where experts from different decision making groups were involved. Another important transport field is related with fuzzy analysis (Teng and Tzeng, 1996; Wang and Lee, 2007; Yeh et al., 2009).

In this section, we propose the use of MAMCDM to determine a fair price for CO_2 emissions. The process should proceed as follows: first, a set of fictitious actors *s* has to be defined. Each represents a different point of view and is included in a context of variable power balance (i.e., the different influence of actors on the final choice of the value is included in the analysis).

Every agent has their own understanding about the criteria that affects the final unitary value of CO_2 emissions and different weights to attribute them (figure 3, point 1). These criteria *c* mostly coincide with the inputs or the specifications required to run an IAM. They can be roughly included in the following main groups: a general definition of the IAMs and their technical characteristics, the future scenario forecasted by each actor, the physical changes and the economic impacts (table 3).

Each of these parameters is a relevant issue in the academic debate. Let us consider, for example, the discount rate to be adopted. Higher discount rates lead to lower values and vice versa. The variation of the unitary CO_2 cost is very high: according to Watkiss et al. (2005), the value decreases from €249/tC to €102/tC when the 1% and 3% discount rates are considered, all other parameters remaining the same. The damage function is another critical parameter. It represents the mathematical transformation of climate change in economic values. Peck and Teisberg (1994) demonstrated the differences in adopting a linear rather than a cubic function (the interval grows from approximately \$34-118/tC to \$34-710/tC).

Group	**Criteria**			
1) Description of the IAM	*Year of publication*	*Unitary emission cost*	*IAM adopted*	
2) Economic impacts	*Reference year*	*Geographical scale*	*Adaptation measures*	*Equity weighting*
	Discount rate	*Pure Rate of Time Preference*	*GDP damage*	*Damage function*
3) Scenario	*Description of the scenario*	*CO_2 concentration*	*Temperature increase*	
4) Physical changes	Sea level rise	Energy use	Agricultural impact	Water supply
	Health impact	Ecosystem and biodiversity	Extreme weather events	Major events/large scale discontinuity

Table 3. List of criteria to be included in a MAMCDM for CO_2 emissions

Similar conditions can be found for the other parameters as well. By adopting the traditional IAM methods, every modeller decides the reference values arbitrarily and the final output is determined by this personal choices. Indeed, MAMCDM proposes a mediation in order to make opinion convergent towards a shared value. Each actor produces their "preferences table" (table 4, part A), in which their points of view relative to the evaluation criteria are expressed. The best value is the actor's optimal solution and range represents their willingness to move from the optimal solution. For example, in table 4 two polarized actors are fictitiously sketched (figure 3, point 2). Actor 1 could represent the point of view of an environmentalist, whereas actor 2 could be the paradigm of an industrialist. The preference function indicates their rough opinion about the criteria. Considering discount rate, it is possible to argue about a potential conflict. The environmentalist prefers an alternative with a high discount rate because of a thoughtfulness about future generations: therefore, he decides to assign to the criteria a high weight (25 points of 100, figure 3, point 3). The industrialist's position is very different (3.5/100), thus establishing a topic of discussion between the two actors. The ranking process begins (figure 3, point 4). According to the preferences of the single actors, the alternatives (table 4, part B) will be ranked in lists of preferences (one for each actor), as expressed in part C of table 4. These lists' preferences are produced by adopting pairwise comparison and will consist of ranked alternatives, which better fit with the actors' perspectives, interests and objectives.

The next step of this process is constituted by the analysis of the ordered lists of preferences (figure 3, point 5). These lists are outranked according to the preference net flows, which can be conceived as the inclination to a preference based on the parameters that fit best to the requirements of each actor.

A - PREFERENCES OF THE ACTORS

		Discount rate	*Equity weighting*	*N° of impacts*	*Carbon Tax*	*CO_{2eq} concentration*	*Temperature increase*
Actor 1	**Preference function**	*max*	*max*	*max*	*min*	*max*	*min*
	Weights assigned	25/100	25/100	19/100	5/100	15/100	11/100
	Best value	2.5	yes	5	n/a	550	2.5
	Range	2	---	1	n/a	n/a	n/a
Actor 2	**Preference function**	*min*	*min*	*min*	*min*	*max*	*min*
	Weights assigned	3.5/100	3.5/100	18/100	30/100	25/100	20/100
	Best value	0	n/a	2	no	650	5
	Range	4	n/a	n/a	----	305	10

B – CRITERIA

	Discount rate	*Equity weighting*	*N° of impacts*	*Carbon Tax*	*CO_{2eq} concentration*	*Temperature increase*
Alternative 1	5	no	5	yes	550	2.5
Alternative 2	10	no	4	yes	450	2.5
Alternative 3	n/a	no	0	no	450	n/a
Alternative 4	n/a	no	4	yes	1150	5.4

Table 4. Example of a preferences table, choice of the criteria and ranked preferences

Finally, the preferences can be graphically ranked. The spatial distance between two alternatives represents the degree of preference. Ranks will be recalculated under different grades of the actors' disposition to negotiate, which is the willingness to distance themselves from their first preference. In this phase, the negotiation plays a main role and the adoption of a GDNSS is required. The degree of flexibility is imposed for each actor deterministically: the point of maximum agreement represents the expected parameters most widely accepted to produce a shared estimation (figure 3, point 6).

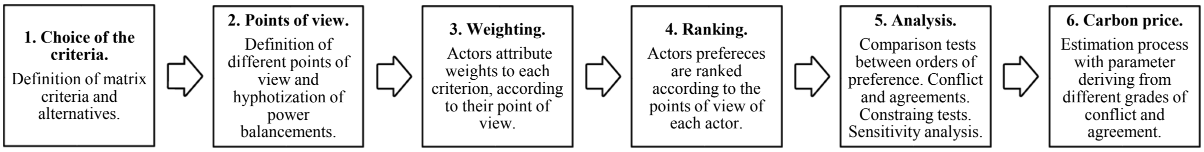

Figure 3. Schematization of the process to obtain a shared price of CO_2 emissions by using the MAMCDM

This estimation process will not rely only on an ex-post mediation of different technical approaches. Indeed, the process results from a deeper analysis, which aims to understand frames and to redefine them through a shared approach. The method is conceptually very different in comparison with the technical valuations, including the ex-post statistical meta-analyses, because it is based on human interactions and decisions taken before the production of a final value.

5. Conclusions and next steps

Most of the strategies currently adopted in transport planning and policy-making recommend that decisions be evidence-based and community-centered. Evidence-based decisions require a thorough understanding of current information regarding the territory considered, as well as the development and analysis of a good number of possible outcomes of different management options. Community-centered decisions should incorporate preferences, values, beliefs, thoughts, and other possible circumstances related to the elaboration of strategies that rank the welfare of the community as a distant first: this implies that an issue should be considered critical, only if conceived as such by relevant social groups. At the political level, (e.g. the Aarhus Convention), there is an attempt to make the decisional process on environmental and transport planning more accessible to the public. Nevertheless, complex aspects have not been based on these premises and are mostly addressed by adopting a mere technical approach. The perspective of the society has not been taken into account adequately, thus leading to misunderstandings and conflicts between different perspectives because a real debate has been prevented and the positions tend to be polarized. This DEAD approach favors decision-makers and postpones, or even omits, a real discussion with citizens.

This is also the case for CO_2 emissions. If we recall the dilemma of the transport planner as expressed in the introduction, it is clear that an evidence-based and community-centered solution has not been found yet. The adoption of the traditional CO_2 valuation methods cannot provide satisfactory results due to the vast ranges of values. From a technical perspective, IAMs seem to be the most effective approach, as they link CO_2 unitary price with environmental changes and economic damages. However, they cannot determine a shared approach, because they only consider the perspective and beliefs of the modeler, which is very subjective.

The statistical meta-analyses are only partially effective to solve this issue, because they do not take into account the dynamics and the mediation processes between the different points of view of the stakeholders (community-centered approach). This paper has introduced the Multiple Agent Multi Criteria Decision Making as an integrative solution to introduce a plural vision in the analysis. It allows the inclusion and weighting of the different points of views of the actors involved in the decision-making process. MAMCDM is designed to support decision making in complex circumstances identical to those posed by many common management decisions (i.e., operations research, computer science, environmental science, engineering, economics, energy, and water sources). A theoretical reconstruction of the process has been developed, revealing its adaptability to this kind of study and its innovative approach to the topic. A first explicative example has illustrated the potentials of this model practically. Further studies have to be carried out, in order to better specify this approach, including the development of a sharable methodology and the calibration on a real case study.

Nevertheless, this is a first step to integrate a plural methodology into a technical one, thus helping the transport planner to provide an evidence-based and community-centered CO_2 valuation.

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