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## A range based Multi-Actor Multicriteria Analysis to incorporate uncertainty in stakeholder based evaluation processes

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Gino Baudry\*†  
Cathy Macharis\*\*  
Thomas Vallée\*

2014/16

(\*) LEMNA - Université de Nantes  
(\*\*) BUTO-MOBI - Vrije Universiteit Brussel  
(†) GEPEA, Université de Nantes

# Range based Multi Actor Multi Criteria Analysis: a way to incorporate uncertainty in the participatory decision process

**Gino Baudry**

*LEMNA, Université de Nantes*

*GEPEA, Université de Nantes*

[Gino.Baudry@univ-nantes.fr](mailto:Gino.Baudry@univ-nantes.fr)

**Cathy Macharis**

*Vrije Universiteit Brussel*

[Cathy.Macharis@vub.ac.be](mailto:Cathy.Macharis@vub.ac.be)

**Thomas Vallée**

*LEMNA, Université de Nantes*

[Thomas.Vallee@univ-nantes.fr](mailto:Thomas.Vallee@univ-nantes.fr)

## **Abstract**

Increasing concerns about environmental and social impacts have made multicriteria analysis (MCA) increasingly popular in decision making processes. The present paper proposes a new methodology which allows taking into account multicriteria aspects, stakeholder's preferences and long time horizon uncertainty. Relying on the MAMCA methodology developed by Macharis in 2000, we develop a new decision making support tool, the range based MAMCA. Within MAMCA, the different possible solutions or alternatives are evaluated on the objectives of the stakeholders. These evaluations can be however uncertain as there might be a lack of knowledge, lack of experience or future predications might be uncertain. By means of Monte Carlo Simulation a range based MAMCA approach is developed to generate several possible states of the world. While a classical MCA would have provided a single final ranking, encouraging the support of an alternative, which can either be the best or the worst one depending on its performance uncertainty in the long run. The range based MAMCA provides a wide range of possible rankings depending on the many possible states of the world. Thus, it provides scorings, rankings of alternatives and the probability they will occur. The new approach is described and shown by means of an illustrative case: the stakeholder support for different biofuel options.

**Keywords:** Multi-criteria analysis, decision making, uncertainty, sustainable development

## Introduction

In recent years, increasing concerns about environmental and social impacts have made multicriteria analysis (MCA) increasingly popular in decision making processes. Sustainability assessment of project planning, policy designing, or other decision making problems need to capture many kinds of data or information, both qualitative and quantitative. MCA provides an operational evaluation and decision support approach that suits complex decision problem setting. Thus, the MCA approach allows dealing with conflicted objectives in an evolving socio-economical system (Munda, 2004; J.-J. Wang et al., 2009).

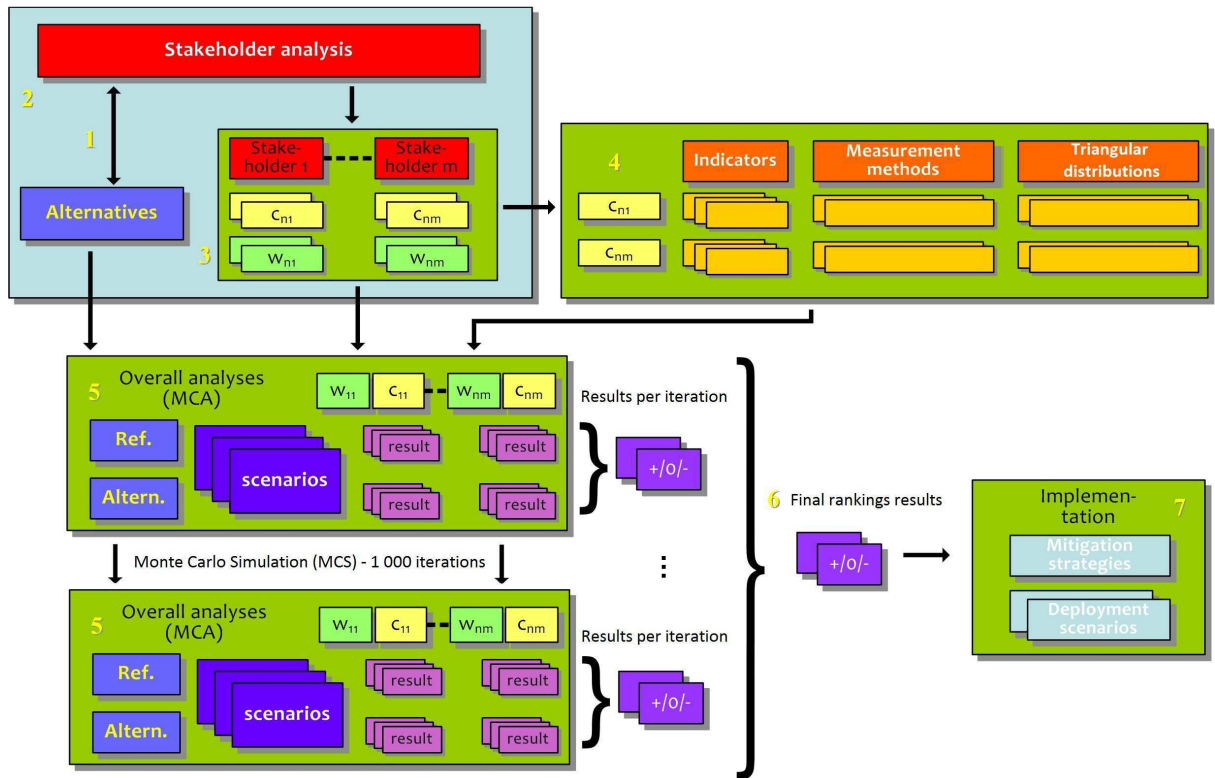
The decision making process usually involves several stakeholders with their own objectives and interests. This makes assessment even more complex. By not taking these different points of view into account, the decision making process will hamper the potential implementation of measures (Banville et al., 1998; Macharis et al., 2009). The Multi Actor Multi Criteria Analysis developed by Macharis (2005) allows taking these different actors into account and at the same time use multi criteria analysis as a basis (Macharis, 2005).

However, long time horizon problems are subject to uncertainty caused by limited available information, a lack of past experience or limited current knowledge on what the longer term impacts will be. Uncertainty of the weights provided by the stakeholders for their criteria can be analyzed by the traditional sensitivity analysis tools. Several articles also provide methods - including fuzzy logic - in the MCA to capture ambiguity, linguistic vagueness and preference (Doukas et al., 2007; Kahraman, 2008; Kunsch et al., 2010). This kind of uncertainty refers to methodological issues which can be identified as a strategic choice between several decision making support analyses. In the present paper, linguistic vagueness is not taken as uncertainty but as a decision or preference according to the available information and current knowledge. In this article we concentrate on integrating uncertainty about the impact of alternatives on the criteria of the stakeholders. Relying on the uncertainty assessment, a Monte Carlo Simulation is applied to provide a wide range of possible solutions. In the next section this new range based approach will be proposed. It is structured according to the common steps of the MAMCA methodology (Macharis et al., 2009). In section 3 we show how the approach would work out in practice by applying it to a biofuel case and we show what type of new analysis tools become available for complex decision making.

## **1. Research methodology: A combined method of MAMCA and Monte Carlo Simulation (MCS).**

Within the MAMCA approach stakeholder involvement is key. After the traditional multi criteria analysis first step of problem description and description of possible solutions, within the MAMCA, a stakeholder identification step is added. Next, the objectives of these stakeholders are identified and they are asked to set their priorities, by giving weights to the objectives. The evaluation of the different possible solutions is made based on these objectives.

As we are mostly working with MAMCA for complex decision problem which often have long time horizon impacts, implications and thus uncertainty, for some values of these evaluations there might be a range of possible values rather than one single value. The MCS are mostly used to simulate complex mathematical systems when a range of different results offers a more realistic approach than a unique solution. The process relies on repeating an algorithm several times, substituting parameters by a randomly generated range of parameters picked from a probability distribution. Each run or iteration offers a different result according to the parameter values i.e. the randomly generated scenario. The several iterations provide a range based output result which depends on the several states of the world generated by the MCS. Thus, this approach offers an interesting tool to deal with models including several varieties of scenario and a long time horizon uncertainty (Basil et al., 2001). Applied to the MAMCA, the MCS allows a better decision making under uncertainty by providing ranges of possible outcomes and the probability they will occur (introduced in step 4).



**Figure 1 – The range based Multi-Actor Multi-Criteria Analysis**

### 1.1. Phase 1: Description of the decision problem

#### Step 1: Defining the problem and the alternatives

Within the MAMCA approach, the first step of the methodology is to define the decision making problem and make a list of possible alternatives (figure 1). According to the problem, alternatives can take different forms such as site locations, technical solutions, policy options or other forms that fit with decision making solutions.

#### Step 2: Stakeholder analysis

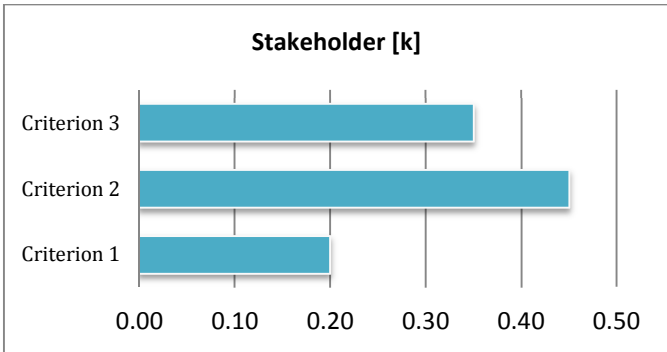
The second step consists in identifying the stakeholders (figure 1) and their relevant objectives. By stakeholder, the present article refers to people who have an interest, financial or otherwise, in the consequences of any decision taken. Thus, an in-depth understanding of both stakeholder's identification and objectives is critical as it allows the appropriately assessment of the alternatives. Every stakeholder group defines their specific objectives which will be used as the criteria on which the alternatives will be evaluated.

#### Step 3: Allocation of weights to the criteria

The third step consists in prioritizing the importance of stakeholder’s objectives / criteria. Several methods such as direct rating, Borda count method, or pairwise comparison can determine the weight to set to each criterion. In this article, weighting as well as pairwise comparisons have to be performed at several stages of the process. As the Analytic Hierarchy Process (AHP) proposed by Saaty (Saaty, 2008) is able to cope with the multi-actor aspects, it has been used for the weighting and the pairwise comparison processes. However, any multicriteria method can be used as long as it can fit the previously mentioned aspects.

The AHP process consists in making pairwise comparison between the criteria or alternatives, depending on the stage of the process. In this present section, the preference intensity of the stakeholders between their criteria is defined by using the 9 to 1/9 Saaty rating scale (Saaty, 2008). Extreme scores, 9 and its reciprocal 1/9, express an extreme preference for a criterion compared to another, while the preference intensity gradually decreases from extreme (9; 1/9) to equal importance (1).

Figure 2 is an illustration of the resulting pairwise comparison matrix of a stakeholder group, revealing preferences between their criteria.



**Figure 2 – Weight allocation per stakeholder**

For the stakeholder (Figure 2), criterion 2 is the most important criterion, representing more than one third of the weight on this stakeholder decision process, while criterion 1 is the least preferred, with only one fifth of the weight. Every stakeholder group might have conflicting objectives but they can also share some common criteria, giving them a potential critical aspect on the final overall analysis. In such cases, potential double counting is not an issue as long as the criterion reflects the real stakeholder preference (De Brucker et al., 2013). For example, greenhouse gas (GHG) savings can be a common criterion of an energy producer and an end user in an energy decision making context.

As mentioned in the introduction, several articles propose to capture uncertainty from ambiguity of linguistic vagueness (Kahraman, 2008; Doukas et al., 2007). In the present paper, uncertainty does not come from linguistic vagueness; we assume that stakeholders can set their priorities according to the available information and current knowledge. Rather, and it is the principal aim of this article, we assume that uncertainty is due to long term horizon uncertainty which involves different possible performances of an alternative on a specific criterion. For example, what will be the biofuel real GHG saving value in a 2020 time horizon compared to the present value? The range based MAMCA approach proposes to handle every potential scenario in between the best and the worst case, capturing biofuel GHG saving performance uncertainty.

## **1.2. Phase 2: Indicators, performance assessment and uncertainty**

### **Step 4a: Definition of the indicators**

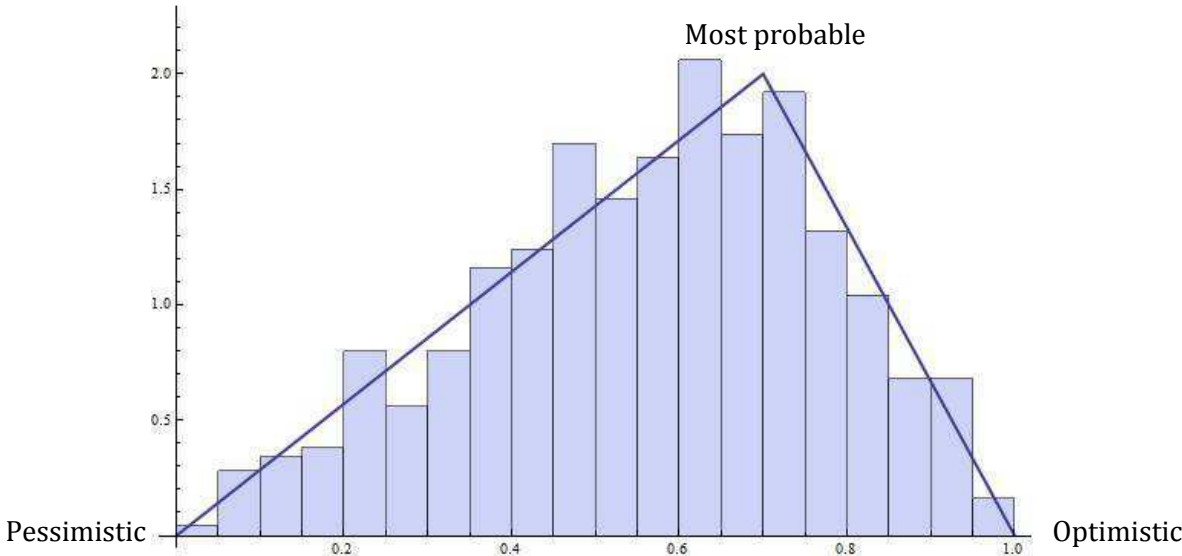
Following the MAMCA approach, the process consists in constructing indicators to measure an alternative's contribution to each criterion. In the next sections, the alternative's performance refers to the measurement of alternative's contribution to each criterion. Based on literature and a wide spectrum of knowledge through expert consultations, each alternative's performance can be assessed. At first, the performance of an alternative is assessed through its capacity to fulfill each single criterion [1, ..., n], then a pairwise comparison is performed between the alternatives [1, ..., k]. The preference intensity between criteria, i.e. the weights, allows aggregating the alternative performances from criterion to stakeholder level.

Addressing long term horizon issues requires anticipating economic, environmental and social issues through different economic sectors. As a consequence, the impact of an alternative on a criterion can be defined in terms of a worst, positive or most probable outcome. Thus, the performance of an alternative can differ depending on several factors. For example, depending on an uncertain oil price in 2030, the production cost of a biofuel can take a wide range of possible values. Furthermore, the production cost can also depend on some carbon tax which has another range of price possibilities and thus its specific uncertainty. The range based MAMCA proposes to capture every specific alternative performance uncertainty in order to provide results analysis within a range, i.e. different states of the world in a long time horizon.

### **Step 4b: Probability distributions construction**



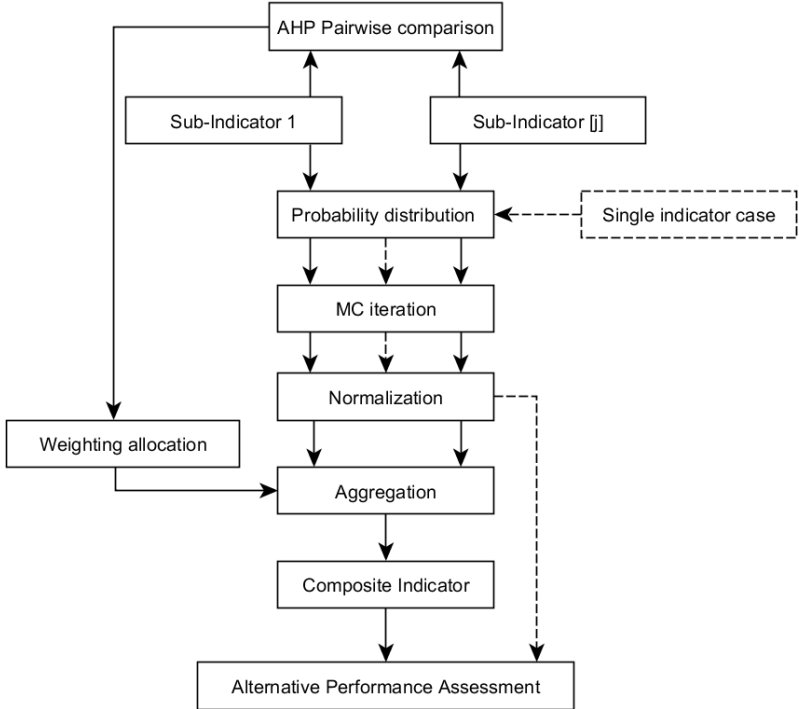
Relying on expert’s consultation and literature surveys, probability function of uncertainties have to be identified to capture the different scenarios which can occur for every alternative’s performance. Thus the process allows fitting each specific alternative uncertainty in terms of alternative’s contribution to each criterion. In the present paper, triangular distributions may be used in order to capture a range of values between the pessimistic, most probable and the optimistic values (figure 3). However, depending on the alternatives and criteria, other probability distribution can be used such as normal and lognormal distributions.



**Figure 3 – Triangular distribution of an alternative performance (Mathematica ®)**

The Figure 3 shows the range of possibilities that a given alternative reaches a performance included in probable, pessimistic and optimistic values relative to a criterion. To illustrate the present triangular distribution (Figure 3), consider a potential GHG saving reduction in 2030. Given the current level of both knowledge and information, the alternative would more likely reach a performance of 70% of GHG savings. Taking into account positive or negative potential impacts on the alternative performance, such as a technological breakthrough, the alternative could reach several levels of GHG saving. For example, the GHG saving performance of a biofuel can be worse or better than its expected level depending on the use of the feedstock, from 0 in the pessimistic case to 100% in the optimistic case (figure 3). The most probable case is 70%. The histogram corresponds to the range of possible alternative’s performance (x axis) as well as the probability it can occur (y axis). For example, a GHG saving of 40% by the alternative is more probable than a value of 90%.

**Step 4c: Focus on composite indicator**



**Figure 4– Composite Indicator construction scheme**

Some alternative performance can be assessed through one indicator such as greenhouse gas savings or several sub-indicators such as ecological impact (water use, biodiversity, soil toxicity and other factors). In the first case, the input generation is performed on the alternative performance’s distribution (Figure 4, dotted line case). In the second case several steps are needed in order to cope with MCS, MCA and composite indicators quality requirements (Nardo et al., 2005) (Figure 4).

The first step consists in identifying sub-indicators as well as their weight, to measure the contribution of an alternative to a criterion according to the stakeholder vision. The weighting of the sub-indicators are performed in the same way as the criteria weighting method (see section 2.2.1.).

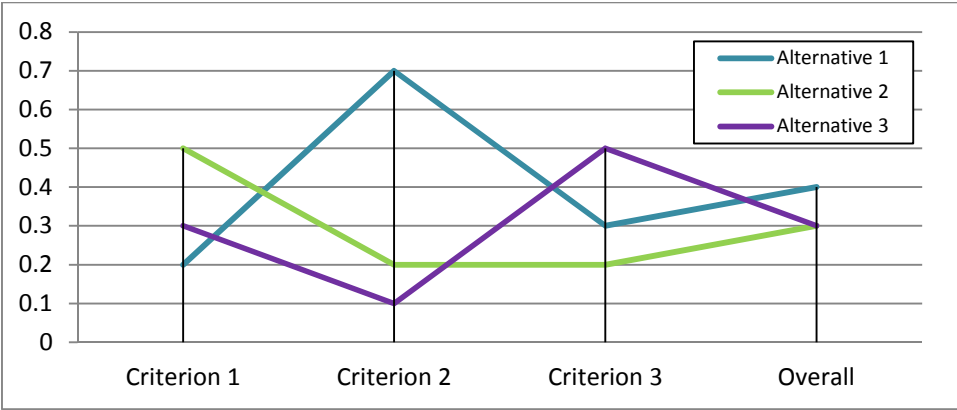
In the next step, triangular distributions are constructed for every sub-indicator, capturing uncertainty through all sub-criteria. Following the input generation, data normalization must be performed to ensure the coherence between the different unit measurements. Finally, according to the sub-criteria weighting results, an aggregation allows summarizing the sub-indicators in the composite indicator, also called CI. For each iteration, a set of sub-indicators inputs are generated by the MCS to finally calculate the alternatives performance by the CI according to the generated scenario.

**Step 5a: Overall analyses per iteration**

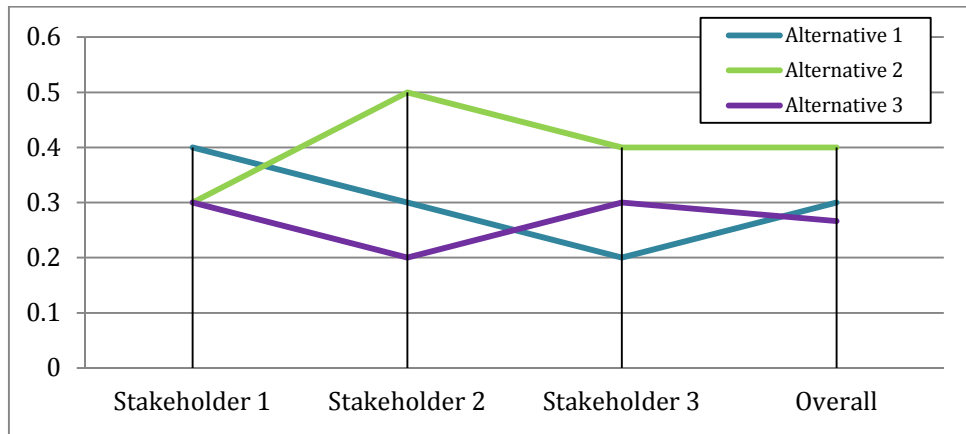
Following the construction of the probability distribution functions of uncertainty, the MCS process consists in randomly generated values in each triangular distribution. Thus, by attributing random performance to each alternative, a state of the world is generated which takes into account all kinds of uncertainty. The next sections refer to those possible states of the world as range based evaluations. In the case of common criteria or sub-criteria, the performance value cannot be issued from two different probability distributions in order to avoid giving the same alternative a different performance relative to the same criterion.

Generating alternative performance allows making a ranking of the identified alternatives considering a given scenario and taking into account the stakeholder’s point of views (step 6). As mentioned previously, the present paper uses the AHP method to perform a pairwise comparison between the different alternatives, but several MCA methods do fit well as long as they can cope with the multi-actor approach such as ELECTRE (Leyva-López and Fernández-González, 2003) or GDSS PROMETHEE (Macharis et al., 1998). The final scorings are obtained by making a pairwise comparison between the different alternatives for each criterion. By using AHP eigenvalues method, each alternative score is included between [0; 1] while the overall scoring sum is 1.

Consider a decision making problem involving three stakeholders, an analysis can be made at different levels: criterion, stakeholder (Figure 5a) or at the overall one (Figure 5b).



**Figure 5a – Final ranking of the stakeholder group 1**



**Figure 5b- Final ranking of all stakeholder group**

In this illustration case (Figure 5a, 5b), the final ranking provides the different stakeholder's point of views:

- Stakeholder 1: Alternative 1 > Alternative 2 = Alternative 3,
- Stakeholder 2: Alternative 2 > Alternative 1 > Alternative 3,
- Stakeholder 3: Alternative 2 > Alternative 3 > Alternative 1,
- Overall analysis: Alternative 2 > Alternative 1 > Alternative 3.

The overall analysis is an aggregation of the stakeholder's score giving the same importance to each stakeholder. The range based MAMCA assumes an equal importance of the stakeholders and thus an equal weighting between the stakeholders groups. As discussed in (De Brucker et al., 2013), this aggregation of scores among the stakeholders should be used with care and should be seen as the sole output of the MAMCA. The main aim is to get insights in the pros and cons of several alternatives for the different actors.

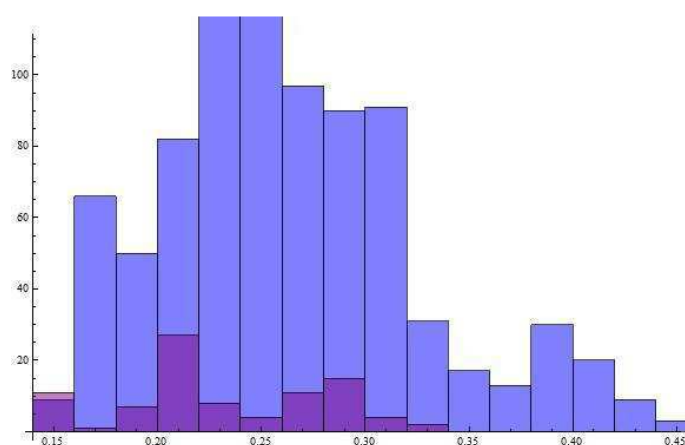
### **Step 5b: Focus on consistency tests**

Qualitative data introduces vagueness in ranking through the Saaty scale methodology which can produce an inconsistent comparison matrix. Thus, consistency tests have to be performed to ensure the transitivity of the preference intensity relative to both stakeholder (phase 1) and expert assessments (phase 2). Concerning the criteria or sub-criteria weighting, in case of inconsistency a discussion with the concerned stakeholder group can be done to reassess the preference intensity (weights). In the second phase, consistency tests also have to be performed on the alternative pairwise comparisons which relied on expert consultations.

The consistency index developed by Saaty (Saaty, 1977) allows checking the level of consistency of the pairwise comparison matrix. It calculates in how far the transitivity

rule has been respected during the pairwise comparisons. However, the literature provides several articles which criticized the method because it allows contradictory judgments and rejects reasonable matrices (Ishizaka and Labib, 2011). Several other alternatives were proposed such as the one of Wang et al. (Y.-M. Wang et al., 2009), based on transitivity rule or the Geometric Consistency Index (Crawford and Williams, 1985). In the present article, the consistency is checked by using Lamata and Alonso methodology (Alonso and Lamata, 2006) which takes into account the structural inconsistency (matrix size) and allows different level of consistency requirements to adapt the criterion to more or less restrictive situations.

Because of random inputs generation, consistency tests must be performed for each iteration. If a single comparison matrix proved to be inconsistent, the entire iteration must be removed before the result analysis stage to avoid bias in rankings (figure 5).



**Figure 6 – Example of some inconsistent iterations (Mathematica ®)**

Figure 6 shows the distribution (y axis) of an alternative final scoring (x axis) where the darkest bars represent the inconsistent iterations, while the lighter bars are the consistent ones. An inconsistent matrix provides final results within contradictions. Thus, to avoid this contradictions bias in alternative performance and final ranking, the inconsistent iterations have to be removed. For example, taking into account the consistent iterations, the score 0.17 is more probable (nearly 65 iterations) than a score of 0.21 (nearly 60 iterations). Without removing that bias, the score of 0.21 (nearly 85 iterations) would have been more probable than 0.21 (nearly 65 iterations), providing a better score to the alternative and possibly a better ranking. Thus, inconsistent iterations need to be removed to avoid contradiction in the final ranking.

This analysis follows the MCS input generation, describing one of the wide range scenario possibilities. However, how can these results be affected by an imprecision on an alternative performance assessment? What if the second alternative fails to reach its most probable performance with respect to different criteria? The objective of the MCS is to provide a wide range of scenarios (each scenario can be interpreted as a particular state of the world) and thus providing a better understanding of the decision making problem when facing an uncertain environment.

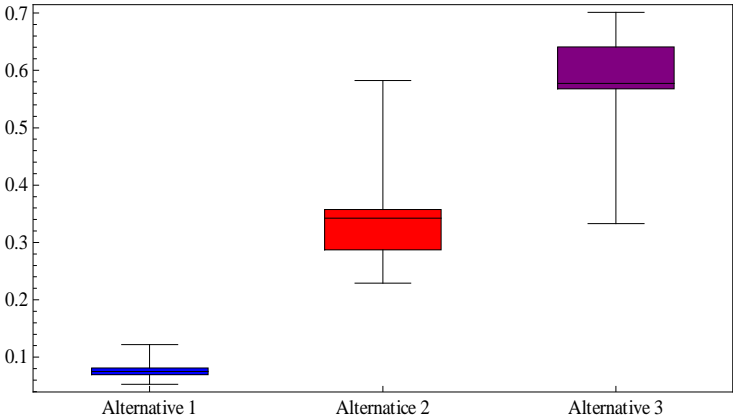
In the present article, a loop from the inputs generation, i.e. the alternative performance assessment, to the overall analysis represents an iteration. Thus, the iteration is repeated several times providing a wide range of scenario possibilities as well as wide range of results analysis. According to Kariznoee et al. (Kariznoee et al., 2014), the number of iteration depends on the accuracy of scorings and weightings, recommending at least a thousand iterations to deal with 3 decimal digits.

**1.3. Phase 3: the range based MAMCA results analysis**

The range based MAMCA provides a clear overview of the points of view of the stakeholders and allows analyzing the results at different levels of aggregation: criterion, stakeholder and overall. A more complete result analysis will be proposed in the illustrative case study in section 3.

**Step 6a: Stakeholder analysis level**

By using the range based MAMCA, a range of performance values is generated providing a range of possible scores illustrated by box plots (Figure 7).



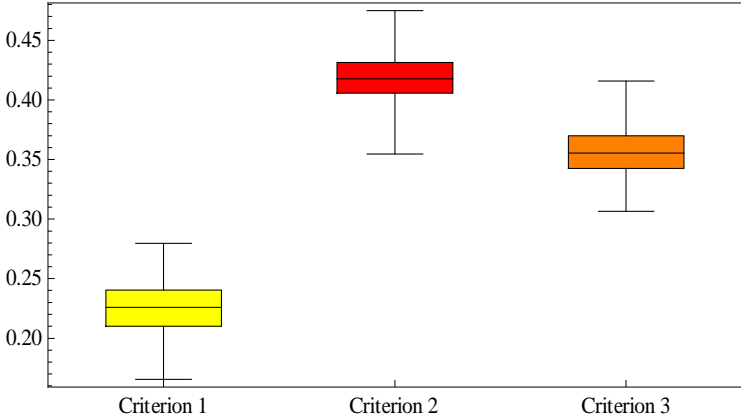
**Figure 7 – An example of final alternatives scoring box plot from a stakeholder’s point of view (Mathematica ®)**

Depending on the uncertainty, alternatives can reach the following scores (pessimistic, most probable, optimistic): Alternative 1 (0.05, 0.08, 0.13), Alternative 2 (0.22, 0.34, 0.6), Alternative 3 (0.35, 0.58, 0.7).

In this illustrative case, the score of the first alternative is never higher than the other two, which means that, whatever its performance among the range of possible values, it cannot be the best solution for the present stakeholder. The most probable ranking is thus alternative 3, 2 and 1 according to the stakeholder’s priorities on criteria. However, the range based MAMCA provides a significant number of scenarios where the score of alternative 2 overcome the score of alternative 1.

**Step 6b: Criterion analysis level**

A disaggregation of an alternative score allows defining the strength and the weakness of the alternative (Figure 8).



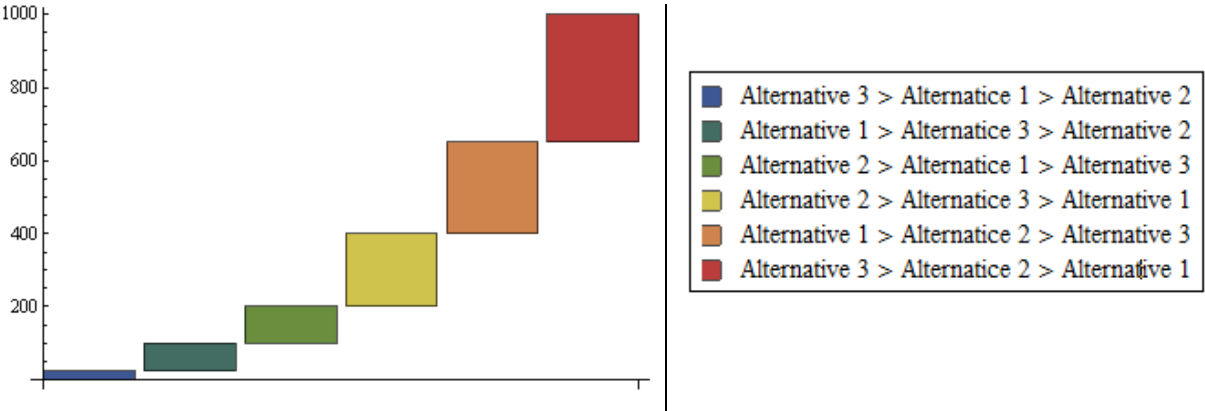
**Figure 8 – An example of final alternative scoring box plot at the criteria level (Mathematica ®)**

In Figure 8, an alternative is assessed through three criteria, allowing identifying criterion 1 as a weakness with a most probable score of 0.23 while criteria 2 and 3 have a most probable score of 0.42 and 0.35. According to the alternative performance uncertainty, i.e. the criterion 1 boxplot variance, even if the performance relative to criterion 1 is the optimistic one, it will always be a weak point for the alternative. Depending on the scenario, both criterion 2 and 3 could be the strength of the alternative. Thus, from the Step 7a and 7b, the alternative’s implementation pathway can be specifically designed to fit the stakeholder’s objectives given the assessed uncertainty.

At this stage, sensitivity analysis can be performed on criteria’s weight to identify which are the most critical criteria. The objective in that case is to identify which criterion is the most influential on the alternatives’ final score. The following section focuses on the thousand final rankings, thus sensitivity analysis can be used to identify critical criterion which are the most influent not on alternatives’ scoring but on the overall final ranking.

**Step 6c: Overall final ranking analysis level**

The range based MAMCA generates a wide range of results. As a consequence, several final ranking possibilities are provided. Figure 9 shows the distribution of the six possible final rankings given the three alternatives.



**Figure 9 – Final rankings (Mathematica ®, 1 000 iteration)**

While Figure 8 focused on alternative switching, Figure 9 focuses on overall final ranking switching. From the left to the right, the chart (Figure 9) shows in ascending order the most recurrent final ranking according to the thousand scenario generations.

Hence, in the present illustration, the ranking “Alternative 3 > Alternative 2 > Alternative 1” represents the most recurrent final ranking with 350 of the 1000 iterations. The second most recurrent ranking is “Alternative 1 > Alternative 2 > Alternative 3”. The present analysis level allows identifying why alternatives 1 and 3 can either be the best or worst alternatives in the two most recurrent final rankings. By doing a sensitivity analysis, it is possible to determine the consequences of a particular criterion on the final ranking (i.e. the variations of the score). An identification of critical criterion allows understanding in which scenario cases an alternative can either be the best or worst solution depending on its performance.



## **Step 6d: Sensitivity analysis**

Several sensitivity analysis methods in AHP environment have been developed (Armacost and Hosseini, 1994; Masuda, 1990; Triantaphyllou and Sánchez, 1997). According to the Alfonso Sanchez (1997), a critical criterion can be defined by two ways:

- The first one focuses on the best alternative ranking alteration (TOP), the most critical criterion denotes the minimum change in the current weight such that the two alternatives will be reversed.
- The second one denotes the minimum change in the current weight such that any alternatives change its ranking (ANY).

A distinction is also made on the “minimum change” term. Sanchez proposed to treat both absolute (ABS) and relative percent (REL) minimum changes. The relative approach proved to be useful in the range based MAMCA in order to compare the sensitivity of a score’s criteria due to the range of data unit and magnitude. For example, a change of 0.01 is very different if the original value is 0.8 or 0.08, thus the relative percent approach makes perfect sense in our methodology.

The sensitivity analysis can be applied on the overall stakeholder ranking to identify the so called Absolute Any (AA), Absolute Top (AT), Percent Any (PA) and Percent Top (PT) critical criterion. The sensitivity analysis can focus on both criteria weight (stakeholder’s level analysis) and alternative final score variations (overall final ranking’s level analysis).

## **Step 7: Alternative’s implementation**

The implementation is the final step of the range based MAMCA, after the decision maker has decided on which alternative to implement. According to the previous analysis in an uncertain environment, an implementation pathway can be designed and additional measures can be established to tackle the barriers and alternative’s disadvantages.

## **3. Illustration of the methodology**

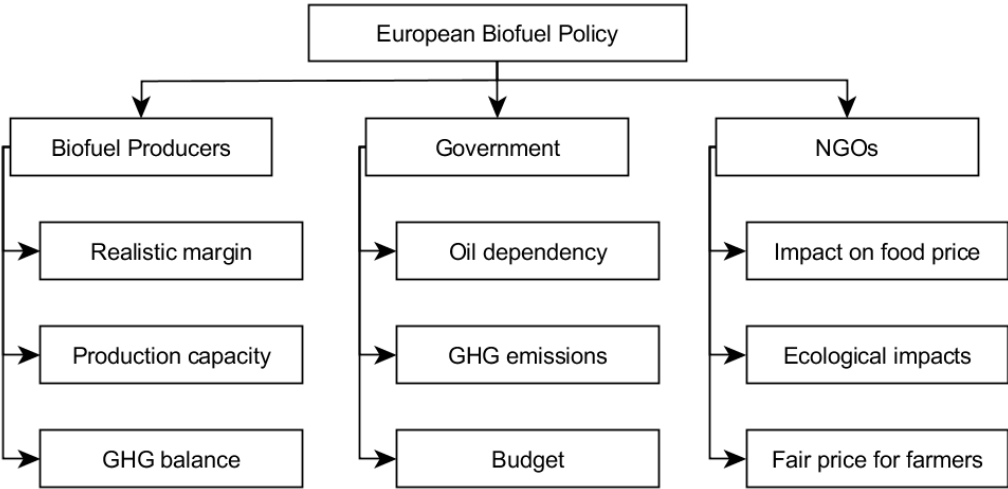
The range based MAMCA method provides a support to decision makers to deal with complex problems featuring conflicting stakeholder’s objectives and limited information in a complex and evolving socio-economic system. The possible divergence between domestic and global priorities through several biofuels aspects, added to long run

distributional implications and uncertainties, make the policy design a really interesting case study to illustrate the range based MAMCA methodology. Thus, the next section proposes to apply the range based MAMCA method on European biofuel policy. As an illustration case, we analyzed a model with three biodiesel alternatives seen through three stakeholder group points of view (Figure 12). Thus, the choice of the illustrative case was made to capture all of the range based MAMCA possibilities: several stakeholder groups, qualitative and quantitative criteria describing multi-dimensional aspects and uncertainties such as ecological impacts or production capacities.

**3.1. Phase 1: Multi-actor and STEEP consideration**

Since 2009, both quantitative and qualitative objectives have been set in the Renewable Energy Directive to reach a 10% share of bioenergy in the transport sector by 2020 (European Parliament, 2009). Several biofuel technologies defined as alternatives in the model present different solution to reach the 10% target, but failed to meet the European sustainable criteria such as land use change. First generation biofuels are available on a large scale but lead to direct competition between energy and food supply. Advanced biofuel technologies, such as Fischer-Tropsch (second generation) or microalgae biofuels (third generation) seem to offer better solutions, but serious challenges remain which have to be overcome to compete with the conventional ones.

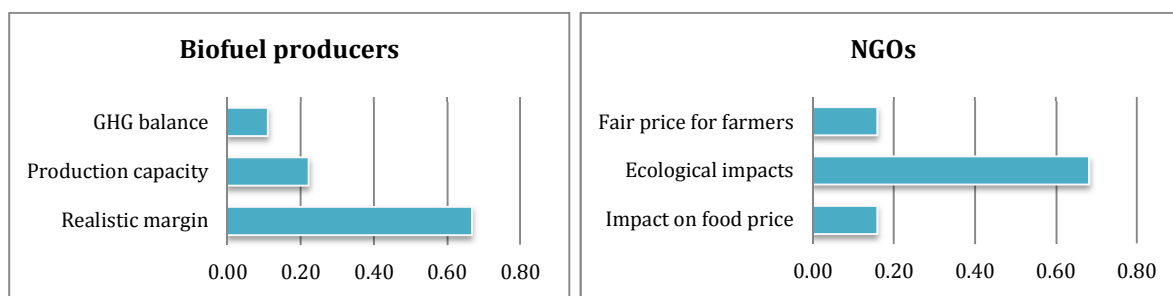
To capture all of the distributional implications of the biofuel supporting policy, the stakeholder groups must include several actors from feedstock producers to North-South organization.



**Figure 10 – range based MAMCA - Decision tree for the illustrative case**

Based on the Turcksin et al. article in which a Belgium study case is described (Turcksin et al., 2011), the illustrative case proposes to focus on three stakeholder groups with conflicting objectives: biofuel producers, government and NGOs (Figure 10). The choice of criteria was made in order to cope with multi-dimensional aspects such as economic objectives (budget, realistic margin, fair price for farmers), social and environmental objectives (impact on food price, ecological impact, GHG) or else technical impacts (oil dependency, production capacity). As mentioned above, the different biofuel generations have several strengths and weaknesses and will be chosen as the three main alternatives to be considered: conventional biodiesel produced from food plants (first generation biofuel), FT-biodiesel produced from energy plants or residue (second generation), and microalgae biodiesel (third generation).

Next, different weights are allocated to assess criteria's priorities in each stakeholder group, based on the study of Belgium.



**Figure 11 – Illustration of weight distribution on criteria for two different stakeholders (based on Turcksin, 2010)**

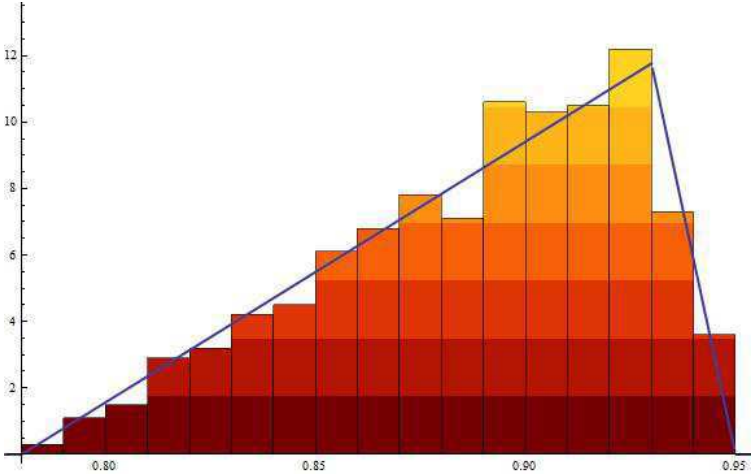
Figure 11 indicates that the economic criterion is the most important for the biofuel producers group whereas the NGOs give the highest importance to ecological impacts (Figure 11). The government gives an equal importance between its criteria: GHG emission, oil dependency and budget allocation. This first step of the methodology will not be more detailed as it is a classical MAMCA application.

### **3.2. Phase 2: Indicators, performance assessment and uncertainty**

#### **3.2.1. Biodiesel performance probability distributions**

Each alternative performance is assessed according to their contribution to single criterion. As mentioned previously, long time horizon involves uncertainty and limited information about each alternative's performance. The range based MAMCA allows

taking into account specific uncertainty to each criterion through MCS scenario generation (Figure 12). For example, the government’s budget impact depends on the production cost of each biofuel, thus, the range based MAMCA allows substituting the possible value of the variable “budget’s impact” by a wide range of potential costs. The same goes with GHG balance according to “technological progress”.



Criterion	Pessimistic	Most Probable	Optimistic
FT-Biodiesel - GHG savings	78%	93%	95%

**Figure 12 – FT-biodiesel GHG savings triangular distribution (Mathematica®, 1000 iterations)**

(E4tech, 2008; European Parliament, 2009)

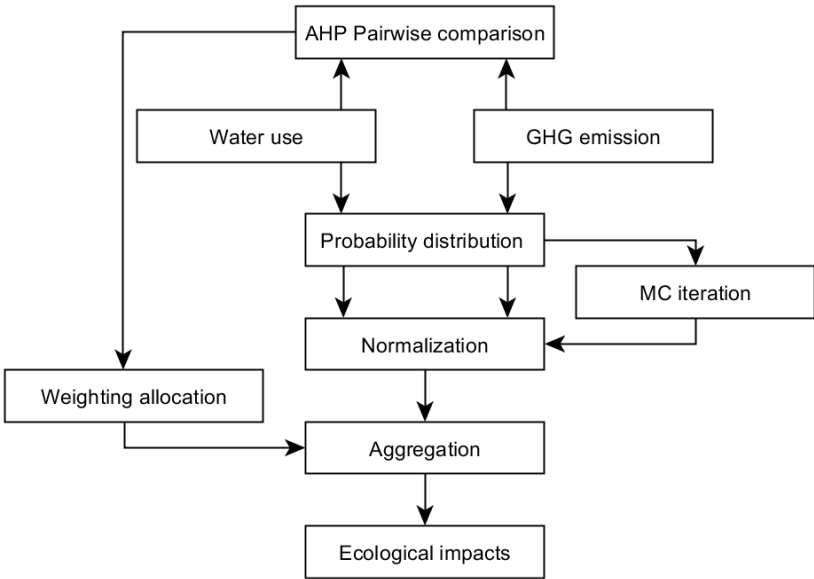
Figure 12 presents the triangular probability distribution of the performance of the FT-biodiesel relative to its potential GHG savings compared to fossil fuel. In the worst case, a GHG reduction of 78% is operated according to energy balance, technical progress or several other factors. In the best case, the reduction can reach a level of 95%, which can be caused by, for example, a technical barrier breakthrough. The most probable scenario assesses a GHG reduction of 78%, which can be the only data used in a classical MAMCA.

The histogram also presents the range of possibilities to the FT-biodiesel performance and the probability they can occur after one thousand iterations. A probability distribution has to be built for each couple criterion/alternative which means 30 probability distributions in this illustrative case (24 indicators, 6 sub-indicators). If a criterion and/or sub-criterion are shared identically by different stakeholders, we draw the value only once (that is for one stakeholder). In our present case, GHG criterion is common to all stakeholder groups (NGOs through ecological impact, see the following section 3.2.2.), and so the total number of probability distributions is reduced to 24.

Each iteration represents a possible state of the world, and one thousand iterations provide a wide range of scenarios capturing long term horizon uncertainties and give additional information for the decision makers.

**3.2.2. Focus on ecological impact composite indicator**

The ecological impact is an illustrative case of composite indicator in the range based MAMCA methodology. In accordance with the actor’s involvement, the indicator has to respect both the stakeholder’s point of view and statistical reliability. In this illustrative case study, ecological impact is assessed through two sub-indicators: GHG emission and water use (Figure 13).



**Figure 13 - CI construction methodology**

The first step is to prioritize the sub-indicators by applying the same method as the criteria weighting allocation (see 3.1). The second step consists in applying the above mentioned methodology (see 3.2.1) on each sub-indicator to capture the uncertainty of biofuel’s performance relative to water use and GHG savings. If the MCS was performed on the aggregate composite indicators directly, it wouldn’t allow capturing specific uncertainty from each sub-indicator.

Following the Nardo’s proposal methodology (Nardo et al., 2005), normalization is performed to ensure the coherence between the different unit measurements (liters and percentage). Finally, an aggregation of the normalized inputs allows us to summarize the ecological impact according to the NGOs preference intensity between water use and

GHG savings. Transparency on sub-indicators is a critical point to ensure that it corresponds to the stakeholder’s semantic analysis.

### 3.2.3. Biodiesel pairwise comparison consistency test

Following the random biofuel performance assessment, the final scorings are obtained by making a pairwise comparison between the biofuel alternatives for each criterion. By using AHP eigenvalues method, each alternative score is included between [0; 1] while the overall scoring sum is 1. The stakeholder’s level consists in aggregating each alternative’s performance-considering the different criterion’s weights.

As mentioned in the methodology part, several iterations need to be removed because of non-consistent matrices generated by the random biofuel performance picking through the MCS process. In this illustrative case study, non-consistent iteration varies from none to less than 5%.

The reason is that qualitative scoring data can introduce non-consistent matrices by using the Saaty rating scale. In the present case, only two of the nine criteria are qualitative data, i.e. 6 of the 24 probability distributions, explaining the low number of non-consistent matrices.

### 3.3. Phase 3: the range based MAMCA results analysis

#### 3.3.1. Stakeholder and criterion’s level analysis

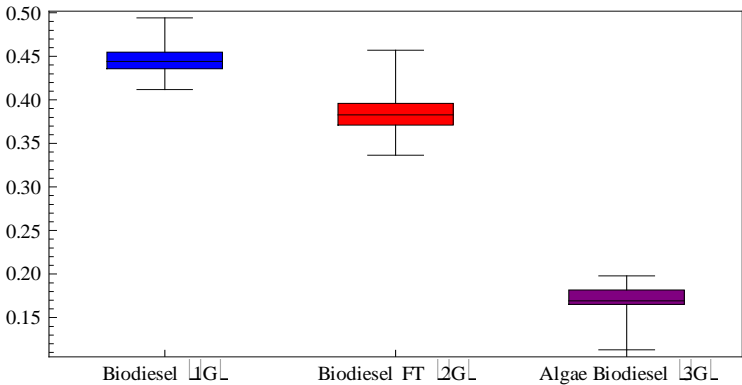
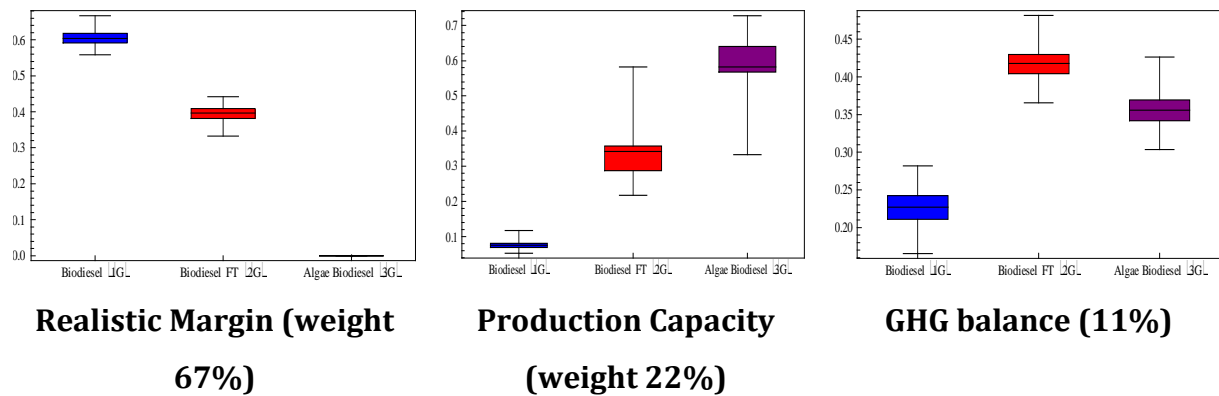


Figure 14a - Biofuel producers final ranking (Mathematica ®, 1000 iterations)



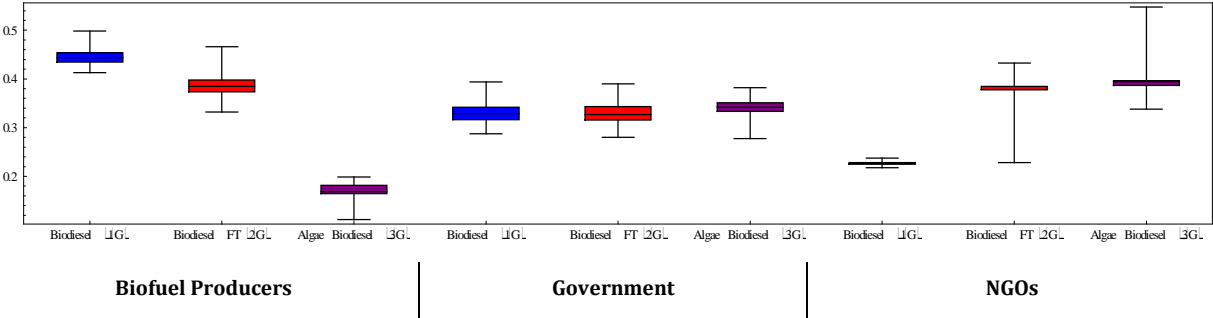
**Figure 14b - Biofuel producers final ranking by criterion (Mathematica®, 1000 iterations)**

Figure 14a provides the biofuel producer final ranking according to the aggregation of his preference intensity between criteria and each performance alternative (Figure 14b). The Y axis represents the score of the biofuel performance while the X axis represents the three alternatives. The more a biofuel alternative contributes to fulfil the criteria objectives, the higher its score is. The overall analysis to the biofuel producer's level reveals that first generation biodiesel is the most relevant alternative. It means that this biofuel fits best to the biofuel producer's priorities. However, depending on the scenario, FT biodiesel can offer a better solution but a criterion level analysis is necessary to interpret this result. According to the box-plot results, whatever the scenario, third generation biodiesel can never be a better solution than the two others from a biofuel producer's point of view. An analysis at the criterion level allows explaining the weaknesses and strengths of the biofuel by identifying the critical criteria.

Figure 14b shows that the biofuel producer interest is mostly the realistic margin, thus it implies a strong preference for the biodiesel (1G). Even if this biofuel is the least preferred according to the two other criteria, final aggregation reveals biodiesel to be the best alternative. However, depending on the production capacity and GHG balance, FT biodiesel can be a better alternative than conventional biodiesel 1G. Despite its performance on production capacity and GHG balance, algae biodiesel suffers a high production cost that makes it a non-viable solution for the biofuel producer.

A common vision and strategy is necessary to reach both quantitative and qualitative biofuel objectives. The present level of analysis facilitates policy implementation taking

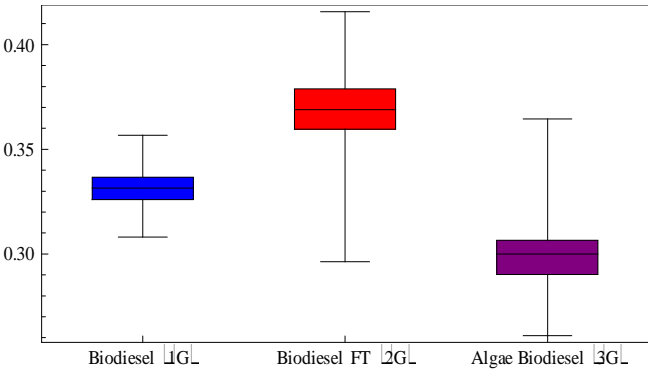
into account both stakeholder’s preference and objectives while assessing the strengths and weaknesses of the biofuel alternatives (Figure 15).



**Figure 15 – Stakeholder’s final rankings per alternative (Mathematica®, 1000 iterations)**

According to the stakeholder’s final rankings (Figure 15), third generation biodiesel cannot be a viable solution for biofuel producers as well as conventional biodiesel for NGOs. However, depending on scenario parameters, FT-biodiesel and conventional biodiesel can be the most relevant solution for the biofuel producer as well as the algae and FT-biodiesel for the NGOs. From a governmental point of view, there is no relevant best solution, but from this multi-actor perspective, FT-biodiesel seems to offer the most acceptable solution for everyone.

The range based MAMCA provides a multi-actor view where every stakeholder group has equal weights (Figure 16).

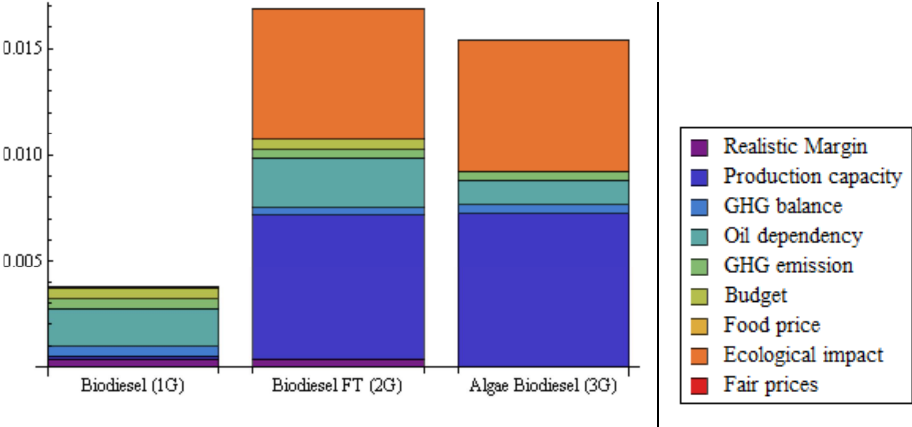


**Figure 16 – Overall final biofuel ranking (Mathematica®, 1000 iterations)**

This analysis gives the most probable ranking and its variance according to the thousand iterations from an aggregation of stakeholder’s points of view, giving an equal weight to every stakeholder group. The most probable ranking is FT-biodiesel, conventional

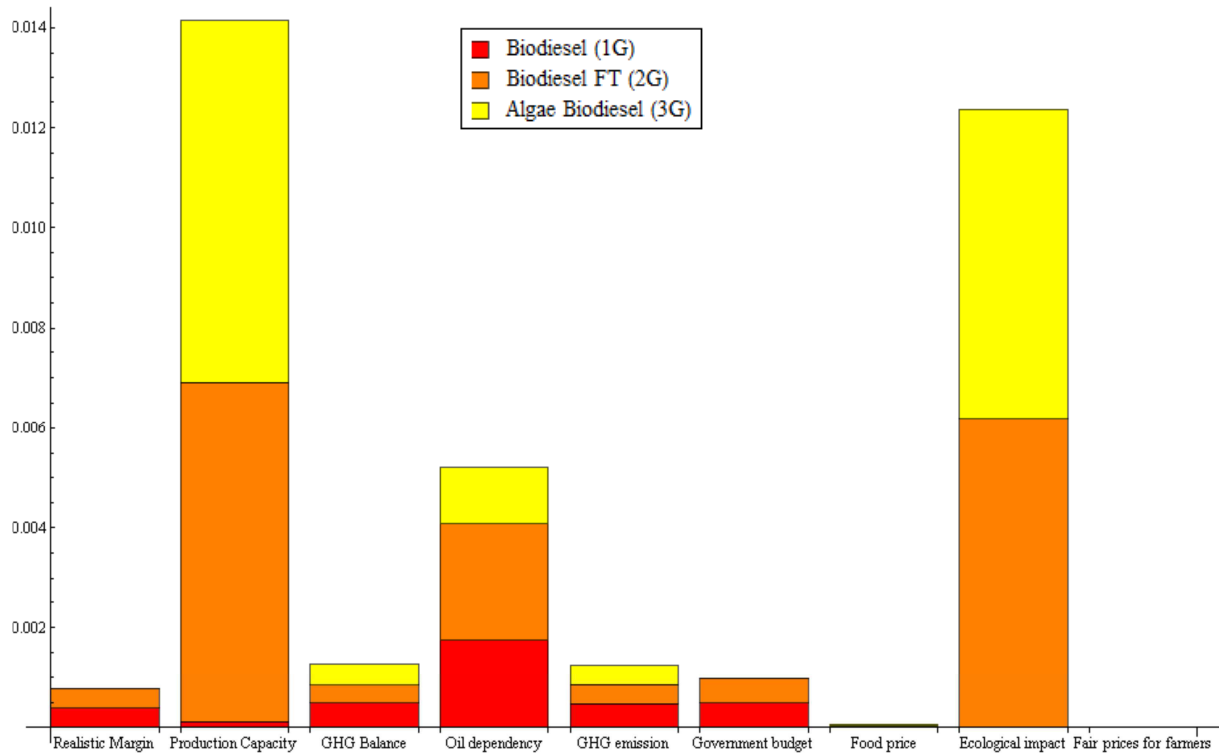


biodiesel and algae biodiesel. However, the variance of each biofuel weighting provided by the range based MAMCA allows both algae and conventional biodiesels to be the potential best solution. Thus, a variance and a sensitivity analysis allow understanding in which cases an alternative is the most relevant alternative.



**Figure 17 - Variance per biofuel (Mathematica®, 1000 iterations)**

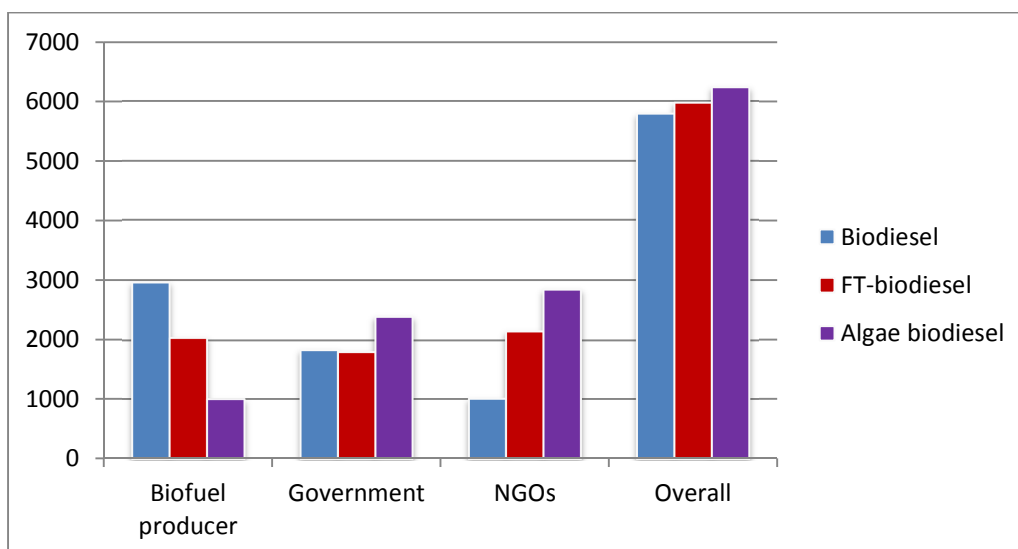
Uncertainty is directly linked to current knowledge and available information, and as such it seems intuitive that the more mature technology is compatible with a lower variance than the advanced biofuel generations (Figure 17). “Production capacities” as well as “Ecological impacts” are the most critical criteria in term of variance. This result fits with the previous biofuel producer’s analysis which already has identified the “production capacity” as a critical criterion for FT-biodiesel. Another way of analyze variance can be to focus on the variance per criteria rather than on the alternatives themselves (Figure 18).



**Figure 18 – Variance per criterion (Mathematica ®, 1000 iterations)**

### 3.3.2. Overall final ranking analysis

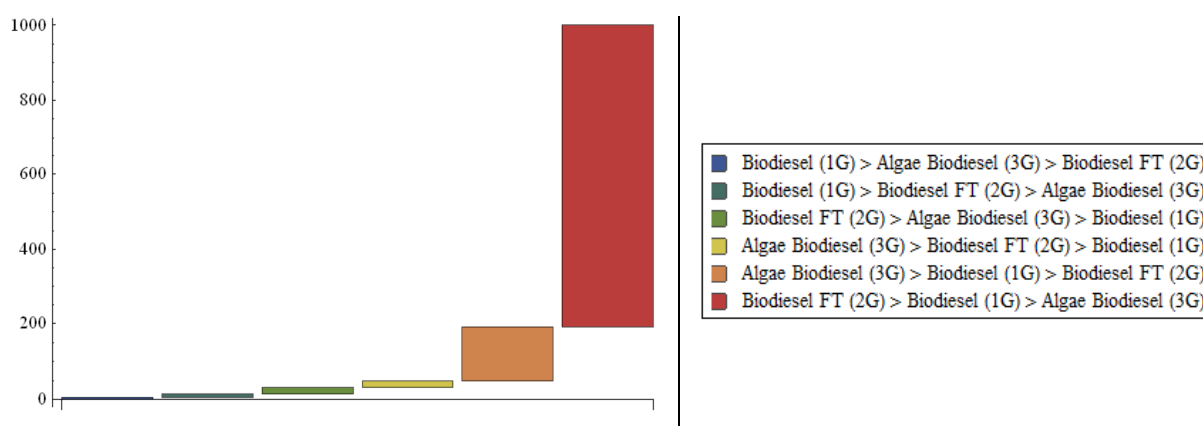
An overall final ranking analysis involves a choice of a particular aggregation method, which can be a critical point. For example, the previous most probable alternative ranking was FT-biodiesel, first generation biodiesel and microalgae biodiesel. Using the Borda count method (Taylor and Pacelli, 2008) which gives, at each iteration and from each stakeholder’s point of view, 3 points to the first alternative, 2 points for the second and one to the last, the following result is obtained (figure 19).



**Figure 19 – Overall final ranking using Borda count method (Mathematica ®, 1000 iterations)**

Figure 19 shows that the rankings of the alternatives from each stakeholder’s point of view based on the Borda count method are almost the same than those in Figure 15. Giving an equal weight to stakeholders, the final overall analysis gives as the first ranking: microalgae biodiesel, FT-biodiesel and conventional biodiesel, which is different from the results of Figure 16. As mentioned previously, stakeholder’s weights are not the principal aim of the range based MAMCA, but Figure 19 highlights that stakeholder’s aggregation method may be a critical point.

Another way to interpret those results is to analyze the final ranking after all iterations. Hence, Figure 20 represents the number of times that a final ranking occurs after the thousand iterations.

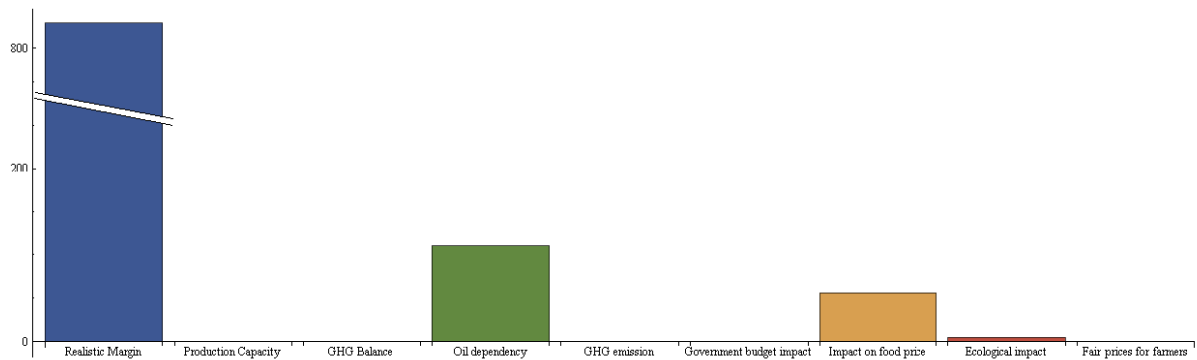


**Figure 20 – Final ranking analysis by iteration (Mathematica ®, 1000 iterations)**

The most recurrent ranking with 808 of the 1000 iterations is the FT-biodiesel followed by the conventional biodiesel and the microalgae biodiesel. It should be noticed that the best ranking as given by a Borda count method occurs on only 17 of the 1000 generated scenarios. However, in order to help biofuel policy implementation, sensitivity tests have to be performed on alternative ranking.

### 3.3.3. Sensitivity analysis

Using the relative and absolute sensitivity analysis allows critical criterion identification. The relative TOP defines the criterion which implies a ranking modification between the top final rankings with the smallest variation of its score.



**Figure 21 – Critical criterion between algae and FT-biodiesel as given by a relative sensitivity approach (Mathematica®, 1000 iterations)**

According to Figure 20, algae and FT-biodiesel can either be the best or worst solution depending on the two most probable scenarios. Applying the relative approach on those biofuels reveals that “realistic margin” is the critical criterion explaining the switch between FT and algae biodiesel on 829 iterations (Figure 21). With an absolute approach, “impact on food price” is the most critical criterion explaining the switch between FT and algae biodiesel. As a consequence, an improvement on algae cost production is the criterion that needs the smallest improvement in relative term to make that third generation the top ranked biodiesel alternative. The same analysis can be performed to understand the overall rankings to the different levels.

### 3.3.4. Policy implications

The last step of the methodology consists in selecting an alternative to implement. The range based MAMCA results allows designing a better pathway to implement an alternative according to the strengths and weaknesses of the alternative itself but also in regards of the uncertainty of those strengths and weaknesses. Depending on the alternative’s specificity, measures can be designed to tackle barriers or disadvantages of an alternative implementation at a stakeholder group level. As an illustrative case, let consider a microalgae biofuel policy support.

For biofuel producers, realistic margin is the most important objective and which is completely not met in the algae biodiesel alternative. High production costs leads to low or no realistic margin depending on the financial policy support. Improvement of the GHG balance can also lead to a better implementation of the third generation biodiesel, but considering the low weight and the high variance of the criterion, the effort must

focus on realistic margin improvement. A possible policy for supporting both GHG and realistic margin could be to use the “double counting of advanced biofuel production” already proposed by the United Kingdom. The principle is to count twice an advanced biofuel production relative to the 10% target, allowing new generation better support and reducing the European budget spending.

Applied to microalgae biodiesel, this policy allows supporting high GHG saving technologies development while reducing the spent of government to reach European renewable energy transport objectives (European Parliament, 2009). GHG saving potential describes a high variance, thus the double counting mechanism must imply a minimum GHG saving threshold to make the third generation a relevant alternative for each stakeholder. Combining the range based MAMCA with an optimization model could lead to the least cost policy assessing the optimal subsidies and GHG saving threshold that can allow a good policy implementation.

For the government, FT-biodiesel is the most relevant alternative according to GHG savings and budget spending compared to microalgae biodiesel. Thus, any financial support needs several measures to ensure the GHG performance of the third generation biodiesel. As mentioned above, double counting policy with threshold GHG savings can lead to reach both environment and economic objectives.

For the NGOs, third generation is the most relevant alternative. Impact on food price constitutes the strength of the algae biodiesel because of high energy density and non-food feedstock use. Ecological impact is the most important criterion for NGOs. Thus several sustainable conditions might be added to the threshold GHG saving, such as good water management. For example, subsidies can encourage the biofuel producers to use wastewater.

#### **4. Conclusion and discussion**

MCA approach deals with multidimensional aspects while the MAMCA method takes into account the stakeholders conflicting objectives. But, when the time horizon of the decision making problem is long, a more robust solution has to be found that explicitly takes in account the possibility of many possible states of the world in the future. In the present paper we proposed a method, the range based MAMCA, specifically designed for taking into account such an uncertainty that is typical in an evolving socio-economical system.

While a classical MCA would have provided a single final ranking, encouraging the support of an alternative, which can either be the best or the worst one depending on its performance uncertainty in the long run. The range based MAMCA provides a wide range of possible rankings by using a MCS which generates many possible scenarios i.e. possible states of the world. We can provide a useful analysis in order to take into account uncertainty in the overall decision making process (Kariznoee et al., 2014). The method allows identifying implementation pathways for alternatives according to their strength, weakness and uncertainty from the stakeholder's point of view. Thus it becomes possible to find compensation measures for the stakeholder groups who suffered disadvantages from the decision making process. In our illustrative case, realistic margin proved to be the most critical criterion. Depending on the technological barriers of both FT-biodiesel and algae biodiesel alternatives, each of them can be the best alternative. In the example, we show that a "double counting policy" for algae biodiesel implementation may take into account all stakeholders' point of view by providing compensation measure for the biofuel producers and may reduce the uncertainty of GHG and ecological impacts.

Further research has to be done in order to improve possible critical points of the range based MAMCA. The final decision will be somehow the one of a particular decision-maker, the government for example. The difficulty can be the stakeholder's weighting which can depend on the number of criteria and their preference intensity (De Brucker et al., 2013) Furthermore, because our approach involves dealing with distributions of optimal ranking of alternatives, the decision-maker should use specific methods to reach a consensus on what is the best ranking of alternatives. That is, and this is our future research, we need a specific tool that provides a pareto optimal final ranking as the result of either the negotiations between the different stakeholders or as the result of some minimization of a given risk aversion criterion.

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