A MULTI-ACTOR MULTI-CRITERIA APPROACH FOR THE INTRODUCTION OF BIOFUELS IN BELGIUM

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ABSTRACT

The Multi-Actor Multi-Criteria Analysis (MAMCA) is a methodology to evaluate different policy measures whereby different stakeholders' opinions are explicitly taken into account. In this paper, this framework is used to identify a long-term biofuel strategy for Belgium. Five scenarios (fossil fuels, bio-diesel, ethanol, biogas and BTL) are evaluated on several criteria, which have been identified by different actors involved in the biofuel supply chain (feedstock producers, biofuel producers, biofuel distributors, end users, vehicle manufacturers, government, NGOs and North-South organizations). It is found that the Belgian government should focus on bio-diesel (through B10) and ethanol (through E85) when establishing its long-term biofuel strategy. The encouragement of these fuels should however happen in accordance with supportive policy measures to overcome difficulties, facilitate their introduction and ensure market success.

Keywords: Multi-Criteria analysis; decision making, biofuels

1. INTRODUCTION

The transport sector has a serious impact on the environment because of greenhouse gas emissions and other vehicle emissions. Next to the emission problem, the energy consumption in transport creates a problem of energy dependency as it relies almost completely on petroleum. Today, biofuels are one of the only direct substitutes for oil in road transportation that are available on a significant scale. Biofuels can be used in existing vehicle engines, either unmodified for low blends, or with cheap modifications to accept high blends. One of the action points of the European Commission is to introduce biofuels in transport. An intermediate target is to reach 5,75% biofuels in 2010 (EC, 2003a). Meanwhile, a new European “Renewable Energy Directive” has recently been accepted by the European Parliament which includes a binding target of 10% renewable fuels (mostly biofuels) in transport by 2020 (EC, 2008). The market introduction of biofuels is expected to be in line with the European strategy.

Despite the actions of many EU countries, the market penetration of biofuels on national levels has been problematic. An assessment report of the European Commission in 2007 (EC, 2007) highlighted that the EU 2005 target was not reached at all and that the EU 2010 target would probably not be met either. Many articles have been focusing on the implementation of the biofuel Directive on a European (Pelkmans et al., 2006), national (Bomb et al., 2007) and city level (Silvestrini et al., 2010) and on the associated implementation problems (Di Lucia and Nilsson, 2007) and pointed out that the commitment of several sectors (government, car makers, fuel companies etc.) and a common vision and strategy are indispensable factors for a successful market introduction of biofuels. Biofuel sectors often cope with many concerns related to economic, environmental, legal and technical issues which should be addressed to get a successful market penetration of biofuels. So far, the stakeholders’ point of view has been questioned by means of face-to-face interviews (Di Lucia and Nilsson, 2007; Bomb et al., 2007), but a common approach that integrates the stakeholder visions into the evaluation process of biofuel strategies is currently lacking. In this paper, a methodology is proposed that addresses the abovementioned problem. This Multi-Actor Multi-Criteria Analysis (MAMCA) (Macharis, 2000) enables the evaluation of several biofuel scenarios, while explicitly taking the point of view of the involved stakeholders into account. As such, an insight is gained in the adoption potential of every biofuel strategy and accompanying measures can be identified to facilitate their introduction.

The focus in this paper lies on the identification of a biofuel strategy for Belgium. The Belgian situation is an interesting case, as the biofuel market is experiencing a delay with respect to its neighboring countries France and Germany. Belgium is a small European country with a very low domestic availability of energy sources. It can thus not rely on a firm agricultural basis to produce feedstock, but it has the economic strength to support it. In 2006, Belgian authorities have implemented a quota system with tax reductions to reach the European target of 5,75% by 2010. Up to mid 2009, filling stations chose whether or not to supply biofuels, which resulted in a very low demand for biofuels by customers and filling stations creating a distribution problem for Belgian biofuel producers (Van de Velde et al., 2009). In July 2009, the Belgian government implemented a fuel obligation system mandating fuel suppliers to include 4% of biofuels in their total sales. Despite these actions to promote biofuels, the actual achievements of biofuels on the Belgian market are rather disappointing. This is probably related to the lack of support by the stakeholders. The current policy measures - quota system and fuel mandate - are mostly driven by the need to comply with European directives, but are not supported by society as a whole. Especially with respect to the new Energy Renewable Directive (EC, 2008), Belgium needs to identify its long-term biofuel strategy, in consultation with the involved stakeholders.

This paper starts with a brief introduction to biofuels, serving as input for the identification of the biofuel strategies. Section 3 gives the theoretical background of the MAMCA approach and provides an overview of some recent applications. Then, the evaluation of the biofuel scenarios through the MAMCA is elaborated (section 4) and an overview of adequate policy measures is presented (section 5) to facilitate biofuel introduction in Belgium. Finally, section 6 summarizes the main conclusions.

2. A BRIEF INTRODUCTION TO BIOFUELS

Biofuels are liquid or gaseous fuels made from biological feedstock (biomass). They can be categorised into 1st, 2nd and 3rd generation biofuels. 1st generation biofuels refer to fuels made from food crops such as wheat, sugar beet and oil seeds. Their sustainable production is currently under review as it is creating land and water competition, diverting land for food production to energy production (IEA, 2008). This has increased the interest in developing biofuels from non-food biomass such as ligno-cellulosic materials including cereal straw, maize stalks and woody material. These 2nd generation biofuels have great potential with respect to life cycle energy, greenhouse gas emissions and cost reductions (Pelkmans et al., 2009). However, they still face major constraints with respect to their commercial deployment as they are produced from more technology-challenging processes that are still in a research or demonstration phase. 3rd generation biofuels refer to biofuels made from algae. These fuels are still in a research and development phase and are seen as an option on the longer term.

The demand for 1st generation biofuels has continued to increase significantly during the past few years. The main liquid and gaseous 1st generation biofuels currently on the market are bio-ethanol, bio-diesel and bio-methane. *Bio-ethanol*, produced by fermentation of sugar or starch crops, can be blended with gasoline fuel in low blends (up to E25 – 25% ethanol and 75% gasoline – in Brazil, E10 in the USA and currently E5 in Europe) without vehicle engine modifications or in high blends (E85 and more) requiring dedicated flexi-fuel vehicles (FFVs) (Faaij, 2006). *Bio-diesel* is produced from vegetable oils or animal fats using transesterification and can be used as diesel additive to reduce levels of particulates, carbon monoxides and hydrocarbons from diesel vehicles. Bio-diesel blends up to 10% (B10) is compatible with all existing diesel vehicles whereas high blends or even pure blends (B100) require changes to the engine and fuel system. Currently, concerns arise with respect to the compatibility of higher biodiesel blends with new particulate filter control systems (Pelkmans et al., 2009). Out of the total share of biofuels in European transport (2,6% in 2007), bio-diesel has the biggest share (75%) of which Germany is the leading producer and consumer, followed by bio-ethanol (15%) and other biofuels such as bio-methane (EurObserv'Er, 2007;

Bomb et al., 2007). *Bio-methane* is made from refined biogas, produced by the anaerobic fermentation of organic wastes including livestock manure, food-processing residues as well as municipal sewage sludge (Faaij, 2006). The raw biogas is subsequently cleaned and purified to produce a high quality methane-rich fuel, which can replace natural gas in gas-powered vehicles. The attractiveness of biogas will however depend on the availability of compatible vehicles and infrastructure and relies almost simultaneously on the success of natural gas technology in transport. So far, bio-methane has been successful in Sweden, and in a number of local initiatives like Lille in France. While most analyses show a net benefit in terms of greenhouse gas (GHG) emission reductions and energy balance, 1st generation biofuels have several (potential) drawbacks such as the impact on food prices (due to competition with food crops), non-sustainable production of biomass feedstock, acceleration of deforestation, negative effects on biodiversity, impact on water use and uncertainty about GHG savings if indirect land use changes are taken into account (IEA, 2008). Many of the problems associated with 1st generation biofuels can be addressed by 2nd generation biofuels, produced from cellulosic materials (lignocellulosic feedstock).

Lignocellulosic ethanol uses a much broader variety of feedstock such as agricultural residues (straw, corn stover), other lignocellulosic raw materials (wood chips) or energy crops (miscanthus, switchgrass etc.) (EBTP, 2010). The production of lignocellulosic ethanol is still in a research and development phase, but it can build on major parts of conventional ethanol plants. *Synthetic biodiesel*, also known as Fischer-Tropsch biodiesel or Biomass-to-Liquid (BTL) are synthetic fuels made from biomass through a thermo-chemical route. This process involves the production of a synthetic gas (syngas), before being passed through the Fischer-Tropsch (FT) process to derive a liquid fuel (IEA, 2008). The focus for vehicle applications mostly lies on FT diesel which is superior to fossil diesel fuel (no sulphur, no aromatics, higher cetane number) and can be blended at all percentages in conventional diesel engines (Pelkmans et al., 2009). So far, synthetic diesel is only considered in pilot and demonstration projects as BTL processes are complex engineering projects (mainly with respect to gas cleaning, scale-up of processes and process integration) and cope with practical problems to be resolved before they become reliable and commercially viable (Faaij, 2006). Once these 2nd generation biofuel technologies are fully commercialised, it is very likely that they will be preferred over 1st generation biofuels. IEA (2008) expects that in the next one to two decades, an integrated 1st and 2nd generation biofuel landscape will emerge in which experiences from using 1st generation biofuels will be transmitted to stimulate the development of 2nd generation biofuels.

3. MULTI-ACTOR MULTI-CRITERIA ANALYSIS

Evaluating transport related projects implies having a method that is able to take into account different conflicting objectives and can reconcile tangible and intangible criteria. Today, five commonly used methods exist: the private investment analysis (PIA), the cost effectiveness analysis (CEA), the economic-effects analysis (EEA), the social cost-benefit analysis (SCBA) and the multi-criteria analysis (MCA) (Macharis et al., 2009). However, the inclusion of stakeholders in the decision making process is an important and for the transport sector often crucial factor for the successful implementation of the measure under consideration. A technique that combines the conventional MCA with the notion of stakeholders in an explicit way is the so-called Multi-Actor Multi-Criteria analysis (Macharis, 2000). Overall, the methodology consists of 7 steps (see figure 1).

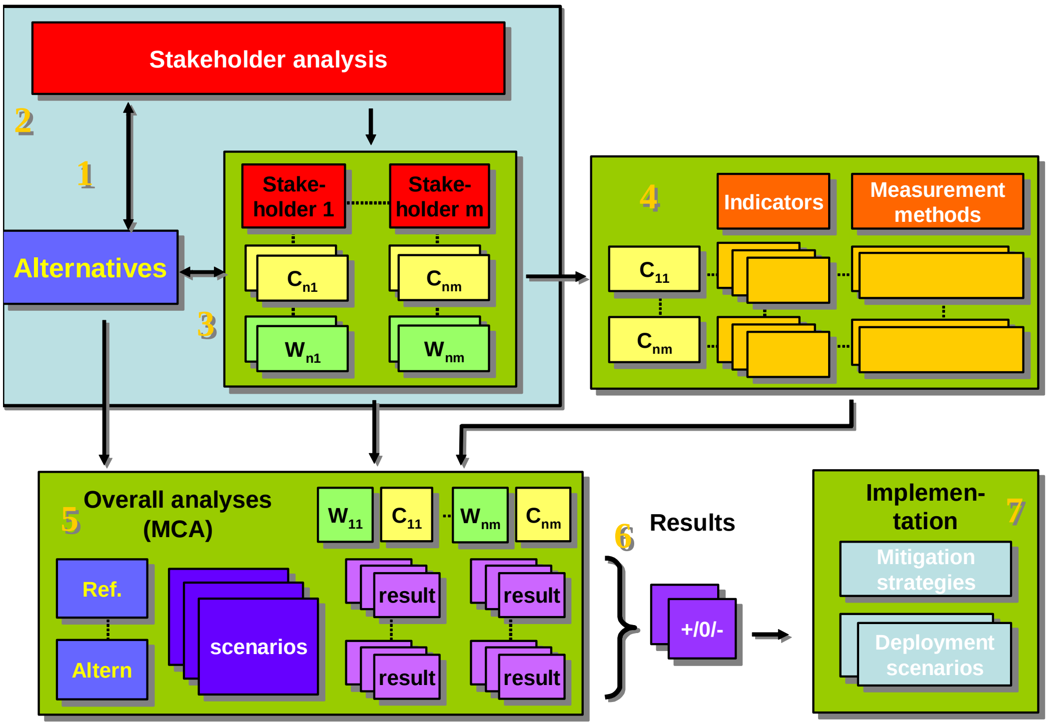

Figure 1 – The 7 steps of the MAMCA methodology

The first step is the definition of the problem and the identification of the alternatives. These alternatives can represent different policy options or actions to be taken. Next, the various relevant stakeholders, as well as their key objectives, are identified. Thirdly, these objectives are translated into criteria and then given a relative importance (weights). The choice and definition of evaluation criteria are based on the identified stakeholder objectives and the purposes of the alternatives considered. Fourthly, for each criterion, one or more indicators are constructed that can be used to measure to what extent an alternative contributes to each individual criterion. Indicators can be direct quantitative indicators (like money spent, reductions in CO2 emissions achieved) or it can be qualitatively scored on an ordinal indicator (e.g. high/medium/low). Moreover, the measurement method for each indicator is also made explicit (e.g. willingness to pay, quantitative scores based on macroscopic computer simulation). This permits measuring each alternative performance in terms of its contribution to the objectives of specific stakeholder groups. Steps 1 to 4 can be considered as mainly analytical, and they precede the "overall analysis", which takes into account the objectives of all stakeholder groups simultaneously and is more synthetic in nature. The fifth step is the construction of the evaluation matrix, aggregating each alternative contribution to the objectives of all stakeholders. Next, the multi-criteria analysis yields a ranking of the various alternatives and shows their weak and strong points. The MAMCA provides a comparison of different strategic alternatives and supports the final decision maker in its final decision by pointing out for each stakeholder which elements have a clearly positive or negative impact on the sustainability of the considered alternatives. Afterwards, the stability of the ranking can be assessed through sensitivity analyses. The last stage of the methodology includes the actual implementation of the policy measure. Once the decision is made, steps have to be taken to implement the chosen alternative by creating deployment schemes.

The MAMCA methodology has already proven its usefulness for several transport related decision problems. It was used to cope with an intermodal terminal location decision problem (Macharis, 2000), for a study on the choice between waste transport alternatives in the Brussels region (Macharis & Boel, 2004), for the location choices of a new high speed train terminal (Meeus et al., 2004), for the evaluation of DHL's hub strategy at Brussels airport (Dooms et al., 2006; Macharis, 2007), in the project 'Night Deli' for the evaluation of different night distribution scenarios (Verlinde et al., 2009) and in the Flanders in Action Process to structure the discussions on how to turn Flanders into a top region by 2020 in terms of logistics and mobility (Macharis et al., 2010). For a complete overview of theory and applications of the MAMCA methodology, see Macharis et al. (2009).

4. MAMCA IN THE CASE OF BIOFUELS

The MAMCA approach in this paper aims to provide an insight in the support by different stakeholder groups for several biofuel introduction scenarios in order to reach the European target of 10% renewable fuels in transport by 2020 (EC, 2008). The different steps associated with the MAMCA procedure are addressed in this section.

Step 1: Defining the problem and the alternatives

The first stage of the methodology consists of identifying the possible alternatives submitted for evaluation. These alternatives can take various forms according to the problem situation. In this case, the problem is related to the European Renewable Energy Directive which includes an overall binding target of 20% share of renewable energy sources in energy consumption and a 10% binding minimum target for biofuels in transport to be achieved by every Member State (EC, 2008). As a consequence, Belgium needs to define its strategy to reach 10% of renewable transport fuels by 2020. There are various strategies to implement biofuels in transport. The most obvious and fastest choice is to blend a limited percentage of biodiesel or BTL to all diesel fuel and a certain share of ethanol to all gasoline fuel. On the other hand, there are a number of advantages when introducing higher biofuel blends, and even pure biofuels (Pelkmans et al., 2006): (1) Using high blends increases the visibility and can be used as a green marketing tool (e.g. vehicle manufacturers supplying biofuel-compatible vehicles, fuel distributors offering high biofuel concentrations, users showing their environmental consciousness by purchasing biofuel vehicles), (2) Only high blends or pure biofuels can really provide an alternative to become independent from fossil fuels, (3) Certain high blend biofuels provide very low exhaust gas emissions and can thus be promoted for direct environmental reasons (air quality) in city traffic. For example, when ethanol is blended with a low percentage, the vapour pressure might increase whereas in high ethanol concentrations the vapour pressure is lower than for fossil petrol.

Based on the technological evolution in vehicle models, the likely biofuel blends on the European markets and the possible interest of certain end user groups (e.g. public transport, agriculture), five scenarios are considered for evaluation with respect to the adoption of biofuels in the Belgian transport system by 2020 (Pelkmans et al., 2008) (see figure 2).

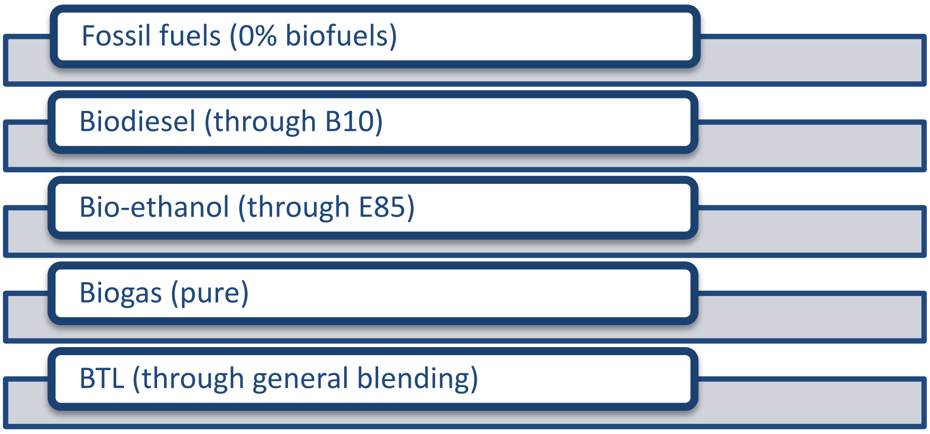

Figure 2 – The alternatives

Step 2: Stakeholder analysis

Unlike a conventional multi-criteria analysis where alternatives are evaluated on several criteria, the MAMCA methodology explicitly includes the point of view of the different stakeholders. Stakeholders are people who have an interest, financial or otherwise, in the consequences of any decision taken. Stakeholder analysis should be viewed as an aid to properly identify the range of stakeholders to be consulted and whose views should be taken into account in the evaluation process. Here, the stakeholders were identified according to the biofuel supply chain (see figure 3). These stakeholder groups were validated at a dedicated workshop for biofuel representatives (Turcksin & Macharis, 2009). The identified stakeholder groups are the agricultural sector, biofuel convertors, fuel distributors, end users, car manufacturers, government and NGOs & North-South organizations. In order to show that the point of view of all stakeholders is equally important, every stakeholder group gets an equal weight of 14,3% (100% for 7 stakeholder groups).

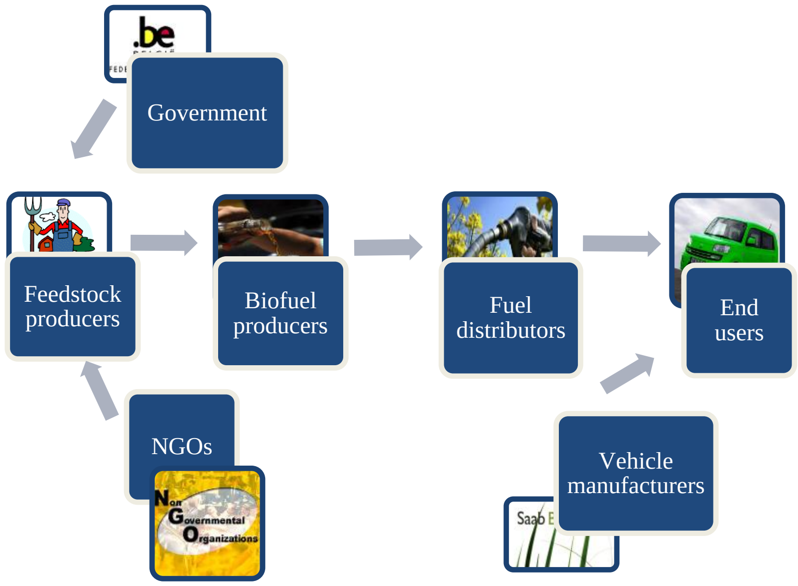

Figure 3 – Stakeholders

The point of view of 31 highly representative stakeholders from 7 different stakeholder groups is taken into account. The feedstock producer group consists of 5 people, representing the agricultural sector, wood sector, biomass based industry, waste processors and traders. The group of biofuel producers includes 5 market players involved in the production stage of biofuels, especially bio-technology companies and the agro-industry. The group of fuel distributors, petroleum industry and filling stations amounts up to another 5 people. The view of the end user group is given by 4 people working in road assistance companies, transport and leasing sector and private and public fleets. The view of vehicle manufacturers, convertors and car dealerships is given by 4 persons. The governmental group consists of 4 people working at different Belgian administrations such as Flemish, Wallonian, Brussels and federal administrations. Finally, the input from NGOs and North-South organizations was achieved through 4 representatives.

Step 3a: Defining criteria

An in-depth understanding of each stakeholder group's criteria is critical in order to appropriately assess the different alternatives. The choice and definition of the criteria is primarily based on the identified stakeholder objectives and the purposes of the alternatives considered. With this information, a hierarchical decision tree can be set up. The MAMCA methodology can make use of identical criteria for every stakeholder group (Macharis et al., 2010; Lebeau et al., 2010) or identify specific criteria for each stakeholder group (Macharis & Stevens, 2003; Macharis et al., 2004). In this analysis, the latter method is used: for each stakeholder group, the evaluation criteria were first tracked by the literature. Next, during a stakeholder workshop (Turcksin & Macharis, 2009), representatives from each stakeholder group had the opportunity to evaluate and validate the pre-defined criteria. Figure 4 renders the final decision tree, in which the different stakeholder groups and their multiple criteria are highlighted.

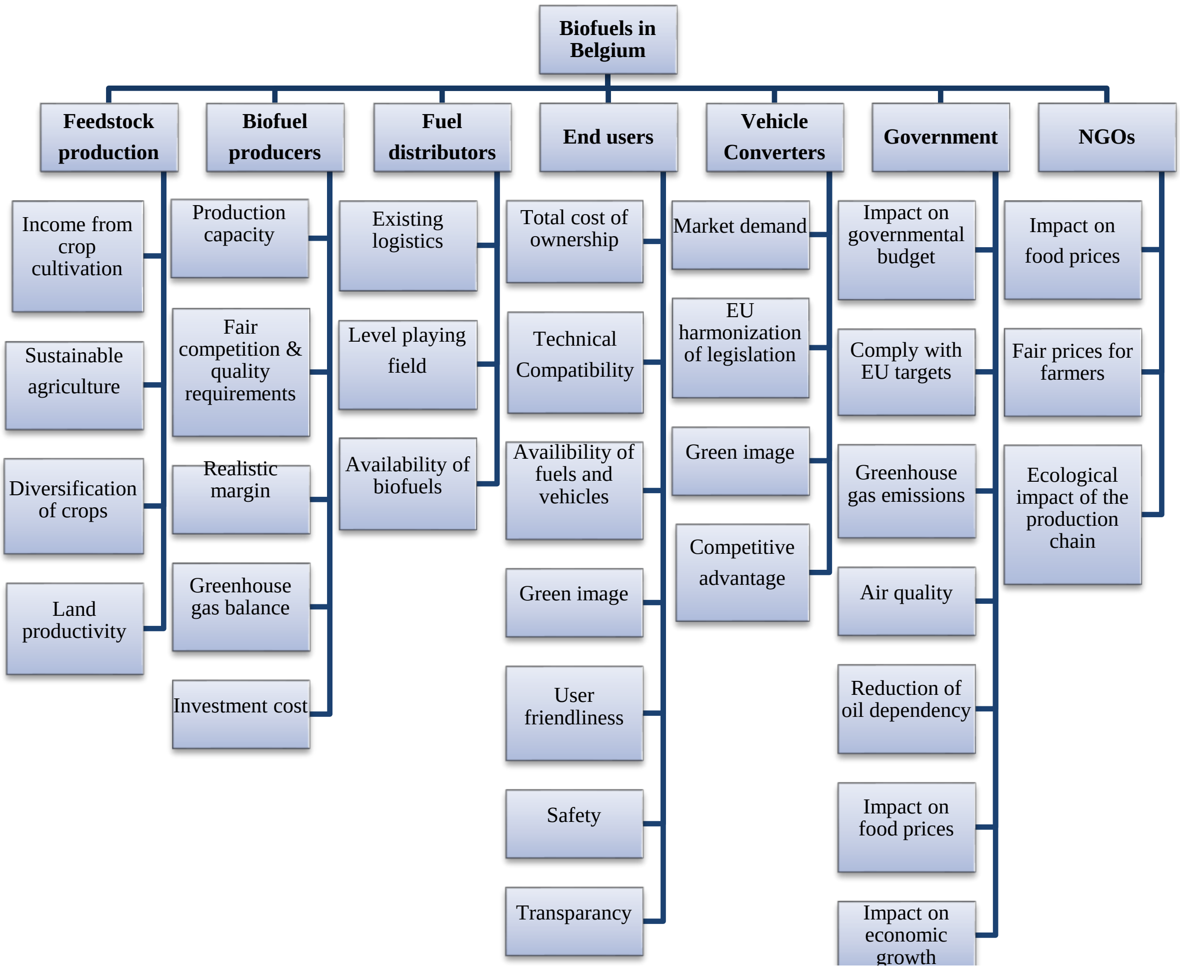

Figure 4 – Final decision tree

Throughout this decision three, it can be observed that the introduction of biofuels is very complex and that it raises several concerns. Biofuels refer to several aspects at the same time - economic, environmental, legal and technical aspects - in which each stakeholder group has his own stake:

Economy

For all stakeholder groups, economic issues are a major concern when it comes to biofuel introduction in Belgium. For *feedstock producers*, 'income from crop cultivation' needs to be at a sufficient level to become commercially viable with regard to international and national competitors. In this respect, 'diversification of crops' to different markets (food, animal feed and biofuels) can reduce risk and serve as income guaranty. The economic issues for *biofuel producers* are especially related with (additional) 'investment costs', use of the 'production capacity' and the production cost difference between biofuels and fossil fuels ('realistic margin'). The profitability of *fuel distributors* will be determined by the 'availability' of sustainable biofuels on the long run and the extra costs related to the construction of refuelling infrastructures and/or conversion of 'existing logistics'. For *end users*, the 'total cost of ownership' of a biofuel compatible car should be at least comparable to that of contemporary transport. High prices (extra purchase and/or conversion costs) for green technologies that do not result in savings are very hard to sell (Wong et al., 1996; Bomb et al., 2007). The consumer consciousness concerning the environment has increased and becomes an important factor in purchase behaviour so that *car manufacturers* can use the availability of green technologies as a 'competitive advantage'. Investments in environmental technologies might become cost-efficient if the initial investment and development costs can be offset by their access to the market ('market demand'). Tax cuts, subsidies, implementation and administrative costs will largely impact the 'governmental budget'. Biofuels are also claimed to bring 'economic growth' as they increase employment in many sectors, and especially in rural areas (JRC, 2008). A common concern for government as well as *NGOs* is the impact that biofuel production might have on 'food prices', as land will be diverted from food production to energy production. Additionally, NGOs are concerned about the negative impacts that biofuel production might have on the poor in urban areas, especially with respect to local labour conditions and land rights ('fair prices for local farmers').

Environment

Environmental concerns are also widely observed amongst the stakeholder groups. These concerns are twofold. On the one hand, a lot of discussion is emerging with respect to the sustainability of biofuels compared to fossil fuels. In most cases, the focus is on the origin of the feedstock and the greenhouse gas emissions associated with its production. However, also the effects related to the use of biofuels should be taken into consideration. Overall, the use of biofuels should happen in a sustainable way that balances the main transport related challenges of greenhouse gas reduction, reducing oil dependency and improving air quality. On the other hand, in times where the ecological footprint of transportation is scrutinized carefully, investing in environmentally friendly technologies might give stakeholders a green label and hence a competitive advantage. For *feedstock producers,* 'crop cultivation' should happen in a sustainable way, without depleting the resources or polluting the environment. The 'greenhouse gas balance' of *biofuel producers* will be largely determined by the emissions associated with feedstock production, transport and conversion to biofuels. For *end users*, the environmental friendliness of the car ('green image') becomes increasingly important in the purchase decision (Turcksin et al., 2010). *Car manufacturers* are also aware of the increasing environmental consciousness of society ('green image'). Investments in biofuel compatible cars today might render them a green image in the future and give them a competitive advantage. In their attempt to lower the level of environmental pollution, the *government* needs to monitor the emission of 'greenhouse gasses' on a well-to-wheel basis and the 'local air quality'. Moreover, the level of 'oil dependency' should diminish to counter future oil crises. Finally, the 'total ecological impact of the production chain', including greenhouse gas and other emissions, water and land use, quality of ecosystems etc. affects the *NGO's* willingness to support the introduction of biofuels in Belgium.

Legal

Biofuel introduction in Belgium should be in line with European legislation. The European Directive 2003/30/EC has set the target to reach 5,75% biofuels in 2010 (EC, 2003a). As a result, the Belgian authorities have implemented a quota system, linked to tax exemptions for a yearly quotum of 380.000 m^3 biodiesel and 250.000 m^3 bio-ethanol. These quota were distributed between 3 Belgian ethanol plants (BioWanze, Syral and Alco Bio Fuel) and 4 Belgian biodiesel plants (Neochim, Proviron, Bioro and Oleon) according to a call for tenders. The main advantages of a quota system are the stabilisation of the biofuel market, the long-term security for biofuel producers, government control over budget loss through the assigned tax reductions and the possibility of specifying conditions for granting the quota However, possible side effects could include that the government is reluctant to increase the quota because of budgetary reasons, the lack of incentives to go beyond the quota, the discouragement of new private initiatives because of the governmental control and the limited market access for other parties (Pelkmans et al., 2006). Until mid 2009, Belgium was confronted with a reluctance of fuel distributors to introduce biofuels in their fuel mix, even with the tax reduction. In 2008, only 115.300 m^3 biodiesel and 24.000 m^3 bio-ethanol were put on the Belgian market, which is below the envisaged quota of respectively 380.000 m^3 and 250.000 m^3 per year (Pelkmans et al., 2009). Hence, in July 2009, the Belgian authorities implemented a fuel obligation system mandating fuel suppliers to include 4% of biofuels in their total fuel sales. Meanwhile, a new European Directive (EC, 2008) has been accepted by the European Parliament which includes a binding target of 10% renewable fuels (mostly biofuels) in transport in 2020. Biofuel introduction in transport will also largely depend on the fuel standards, issued by the European Committee of Standardization (CEN). The EU Fuel Quality Directive 2003/17/EC (EC, 2003b) defines the current fuel quality standards (EN590 for diesel and EN228 for gasoline). The CEN diesel standard EN590 accepts up to 5% biodiesel by volume and the CEN gasoline standard EN228 limits the maximum amount of bio-ethanol in gasoline up to 5% by volume and up to 15% by volume for ETBE. An adaptation of current fuel quality standards to allow a higher share of biofuels is necessary to achieve future targets. Therefore, the CEN was mandated by the European Commission to work towards an increase up to 10% biofuels by volume. For *biofuel distributors*, fuel standards are a indispensable condition to match their production process to the necessary fuel quality. Moreover, uniform rules for conventional and alternative fuels are needed for the creation of a ‘level playing field’. *Car manufacturers* are also in need of fuel quality standards in order to design their vehicle and engine models towards the fuel specifications of the alternative fuel, which includes warranty. For them, a ‘European harmonization of legislation’ is crucial so that the focus can be laid on the European market instead of national markets each having their own fuel requirements. From the *governmental* point of view, the compliance with ‘European targets and directives’ is a major concern.

Technical

Biofuels are also associated with technical and performance issues. Technical concerns arise with respect to the compatibility of vehicles and filling stations with blends of biofuels. Low blends (up to the limit posed by the fuel standard, 5%) can be used in existing vehicles and fuel infrastructures. High blends and pure blends require extra fuel pumps and material changes in the infrastructure and the vehicles. Performance issues may arise with regard to the limited driving range because of the lower energy content of biofuels. However, biofuels can also improve engine performance. Biodiesel can enhance lubricity properties whereas bio-ethanol may act as an octane enhancer and improver of combustion (Van de Velde et al., 2009). For *end users*, the 'technical compatibility' and the 'availability' of a range of biofuel compatible cars and filling stations will play a major role in the adoption of these vehicles. Real as well as perceived availability is important as even positive attitudes might result in low purchase intentions because of low perception of availability (Vermeir & Verbeke, 2008). Additionally, the degree of 'user friendliness' (driving range and performance) and 'safety' (and perception of safety) needs to fulfil the customer's expectations. At all times, sufficient information will make the whole process 'transparent' and easy to understand and can steer end users towards biofuel vehicles.

Step 3b: Allocation of weights to the criteria

In order to let the stakeholders express their preference for the different criteria, weights are allocated. There exist several methods for determining the weights: direct rating, point allocation, trade-off, pairwise comparisons, etc. The latter procedure, developed by (Saaty, 1980), proves to be very interesting in this case. The relative priorities of each element in the hierarchy are determined by comparing all the elements of the lower level against the criteria with which a causal relationship exists. For this purpose, the decision making software Expert Choice based on Saaty's Analytical Hierarchy Process (AHP), was used. Figure 5 shows a screenshot of the online survey, where each stakeholder had the opportunity to indicate his preference intensity for a specific pair of criteria in a user friendly environment. By means of the rectangular bars, stakeholders could attach different gradations of importance, ranging from extremely more important to extremely less important.

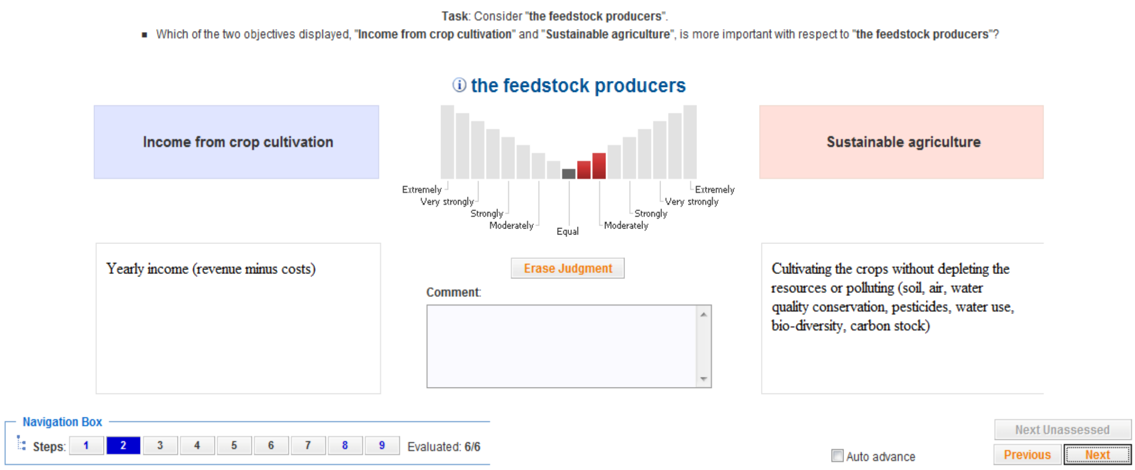

Figure 5 – Screenshot of Expert Choice software

Figure 6 gives the results of the weight distribution. As different members within a stakeholder group were consulted, the geometric mean is calculated to bring the evaluations together (suggestion of Saaty (1995)).

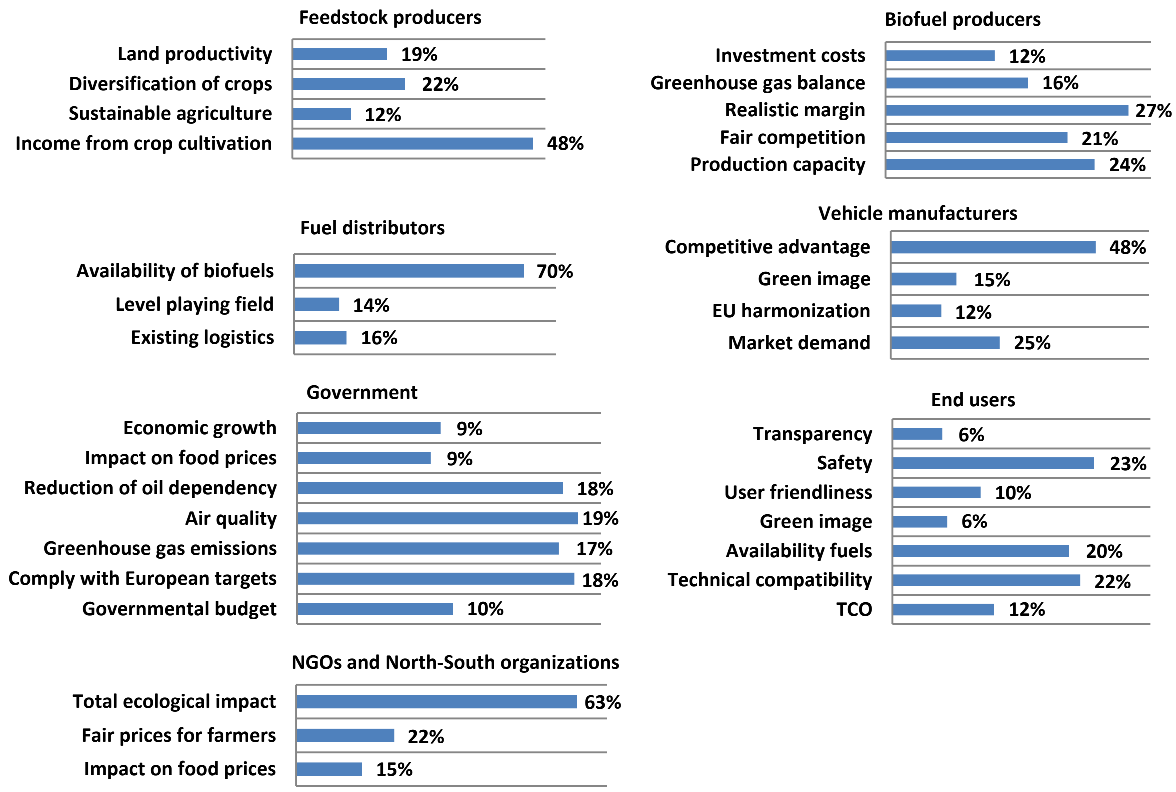

Figure 6 – Weight distribution

Not surprisingly, the economic criteria get the highest preference from feedstock producers, biofuel producers, fuel distributors and vehicle manufacturers when it comes to the introduction of biofuels in Belgium. The highest priorities for end users are related to technical and performance issues such as safety (-perception) and compatibility. The Belgian government and NGOs are rather concerned about environmental issues like reducing greenhouse gas emissions, improving air quality, reducing oil dependency and lowering the ecological impact of the production chain. The only legal aspect that gets a high priority is the compliance of Belgian legislation with European targets.

Step 4: Criteria, indicators and measurement methods

In this step, the previously identified stakeholder criteria are 'operationalized' by constructing indicators that can be used to measure whether, or to what extent, an alternative contributes to each individual criterion. Indicators are usually, but not always, quantitative in nature. The indicator construction follows several stages, as illustrated by figure 7.

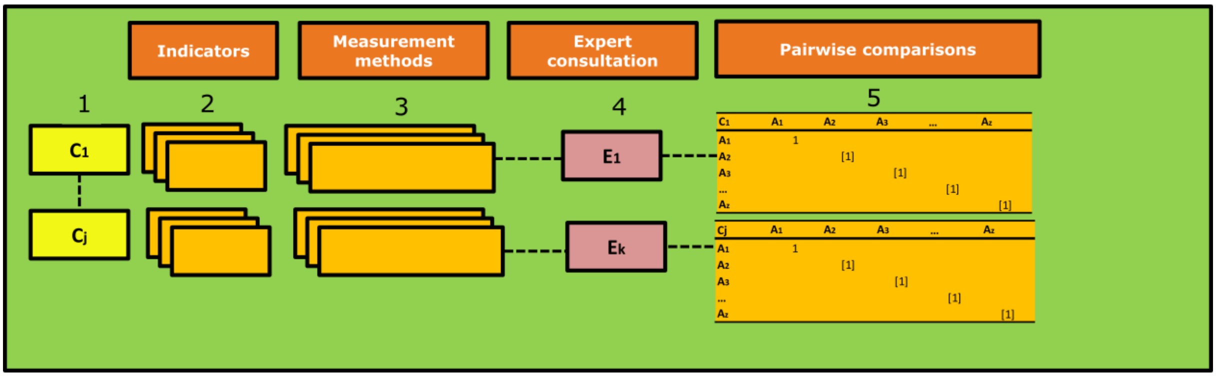

Figure 7 – Indicator construction

First, the choice of the criterion is made for which the indicator will be built. Next, the indicator is constructed that allows measuring the contribution of each alternative to that specific criterion. Subsequently, the measurement method (quantitative or qualitative) is made explicit. Based on literature and/or expert consultations, each alternative performance can be measured in terms of its contribution to the specific criterion. Finally, pairwise comparisons of the alternatives with respect to the specific criterion can be made, based on the Saaty scale (Saaty, 2008) (see table 1).

Table I – The Saaty scale for pairwise comparisons

	Definition	Explanation
1	Both elements have equal importance	Both elements contribute equally to the criterion considered
3	Moderately higher importance of row element (RE) as compared to column element (CE)	Experience and judgment reveal a slight preference of RE over CE
5	Higher importance of RE as compared to CE	Experience and judgment reveal a strong preference of RE over CE
7	Much higher importance of RE as compared to CE	RE is very strongly favored over CE, and its domination has been demonstrated in practice
9	Complete dominance in terms of importance of RE over CE	The evidence favoring RE over CE is of the highest possible order of affirmation
2, 4, 6, 8 (intermediate values)		An intermediate position between two assessments
1/2, 1/3, 3/4, … 1/9 (reciprocals)		When CE is compared with RE, it receives the reciprocal value of the RE/CE comparison
Rationals: Ratios arising from the scale		If consistency were to be forced by obtaining *n* numerical values to span the matrix
1.1-1.9: For tied activities		RE and CE are nearly indistinguishable; moderate is 1.3 and extreme is 1.9

In this analysis, the pairwise comparisons of the alternatives with respect to the criteria of all stakeholder groups have been made by biofuel experts from different institutions (Vrije Universiteit Brussel, Flemish Institute for Technological Research and Université Catholique de Louvain). By letting experts assign the performance values, a scientific and solid foundation in the evaluation process of alternatives is provided.

Step 5: Overall analysis and ranking

In order to assess the different alternatives, any multi-criteria decision analysis can be used. In fact, the second generation multi-criteria analysis methods, the Group Decision Support Methods (GDSM) like GDSS-PROMETHEE (Macharis et al., 1998), AHP (Saaty, 1989) and ELECTRE (Leyva-López & Fernández-González, 2003) are well suited for application in the MAMCA methodology as they are able to cope with the stakeholder concept. In this step, the evaluation of the alternatives is inserted in the evaluation table no matter what kind of method chosen.

For the application under consideration, the software tool Expert Choice was used (ExpertChoice, 2000), based on Saaty's AHP method. This software combines the weight allocation, performed by the stakeholders and the performance valuation of the alternatives, assigned by the experts.

Step 6: Results of the MAMCA

The MAMCA developed in the previous step leads to a classification of the investigated biofuel introduction scenarios. At this stage, a sensitivity analysis can be performed in order to verify if the result changes when the weights are modified. More important than the ranking, the MAMCA allows revealing the critical stakeholders and possible drawbacks of a solution for a certain stakeholder. The MAMCA provides a comparison of different strategic alternatives and supports the decision maker in making his or her final decision by pointing out for each stakeholder which alternative is preferred. Figure 8 shows the multi-actor view. On the horizontal axis, the 7 stakeholder groups are displayed. The rectangular bars at the bottom and the corresponding values on the left axis indicate that each stakeholder groups was given the same weight as they are equally important. The values on the right axis represent the scores of the different policy measures under consideration. On the 'OVERALL' axis, a general prioritization of the proposed policy scenarios is given for all stakeholders and for all criteria.

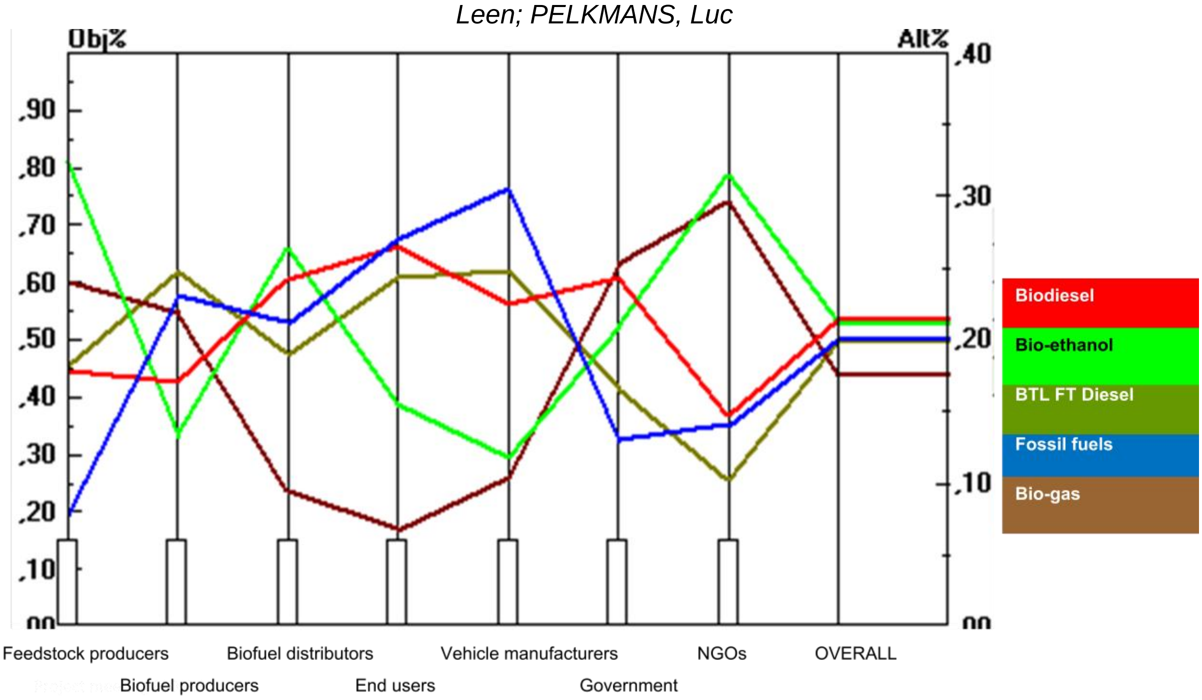

Figure 8 – Multi-actor view MAMCA

Out of figure 8, bio-diesel and ethanol are considered to be the most effective scenarios for biofuel introduction in Belgium. This result is confirmed by other studies such Pelkmans et al. (2008) and Bomb et al. (2007) indicating that a combination of these 2 scenarios will be able to reach the high biofuel shares and (most probable) the EU target of 10% by 2020. For bio-diesel, the main roll-out will be through general blending (B10). For bio-ethanol, the focus should be on high blends (E85), especially in niche markets. Most stakeholders have a similar idea on the prioritization of bio-diesel, except for the NGOs. Bio-ethanol gets a lower support from biofuel producers, end users and vehicle manufacturers. A deeper insight into these views can be obtained by investigating each stakeholder group individually. Figures 9 to 15 show the outcomes for respectively the feedstock producers, biofuel producers, fuel distributors, vehicle manufacturers, end users, government and NGOs.

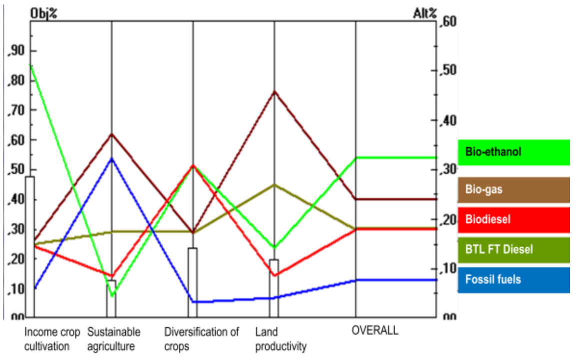

Figure 9 – Feedstock producers

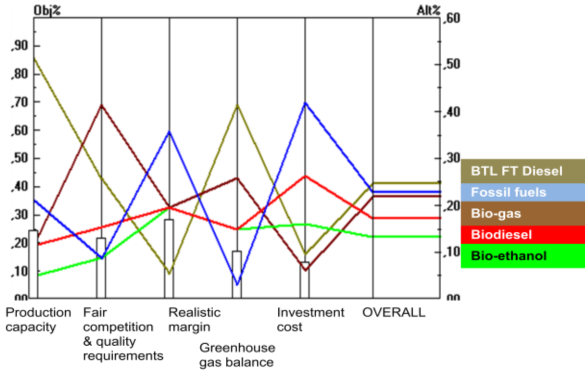

Figure 10 – Biofuel producers

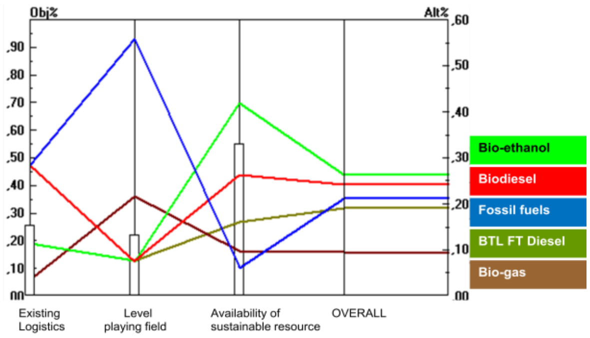

Figure 11 – Fuel distributors

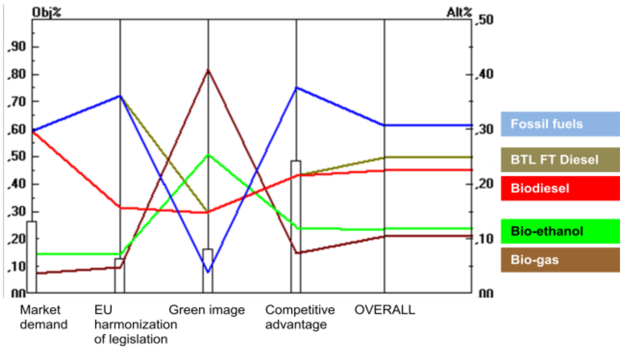

Figure 12 – Vehicle manufacturers

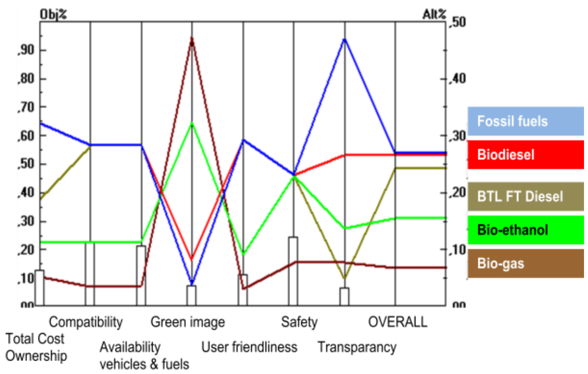

Figure 13 – End users

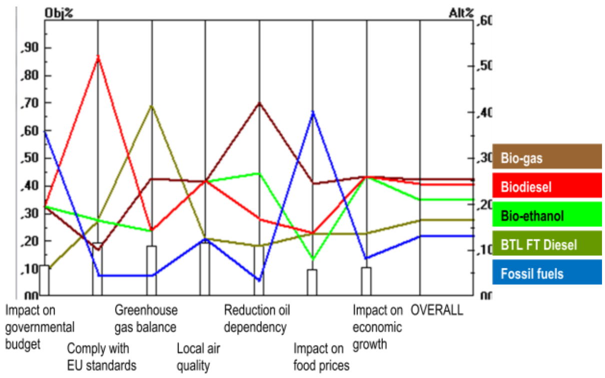

Figure 14 – Government

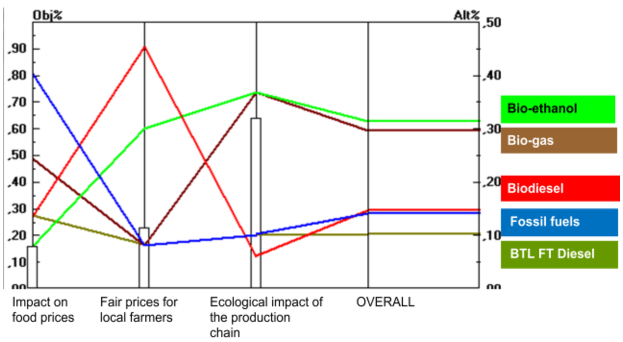

Figure 15 – NGOs & North-South organizations

For *feedstock producers (figure 9)*, income from crop cultivation (gross margin per hectare) and diversification of crops to different markets (food, fuel, animal feed) are the most important criteria to be obtained. Bio-ethanol is ranked high with respect to these criteria and is therefore the most preferred scenario for feedstock producers, followed by the production of biogas, which contributes the most to the other two goals; sustainable agriculture (measured by the use of pesticides, water and eutrophication) and land productivity (in GJ per hectare). For the existing *Belgian production plants (figure 10)*, the production of bio-ethanol and bio-diesel is not the best option in the realization of their objectives. Their production facilities are underused and market access is difficult ('production capacity'). The increasing trend towards 'dieselification' in Belgium also creates a less favourable position for gasoline replacing fuels like bio-ethanol. Taking into account the high expected diesel demand and its easy market accessibility, BTL is the best option for biofuel producers. Moreover, this fuel will be less confronted with cheap feedstock from international markets ('fair competition') and provides the best results with respect to the 'greenhouse gas balance'. As this fuel is still in a research and development phase, it is expected that BTL will be less favourable with respect to the 'realistic margin' and 'investment cost'. For *fuel distributors (figure 11),* fossil fuels are preferred over biofuels when it comes to the use of infrastructure and the existence of a level playing field. Conversely, fossil fuels are ranked very low with respect to the security of supply and the sustainability ('availability of sustainable resource') of this fuel. Production capacities of bio-ethanol and bio-diesel are already available in Belgium and able to reach the 10% target of biofuels by 2020. Because of the large importance that fuel distributors attach to the 'availability' criterion (see the large rectangular bar for this objective), bio-ethanol and bio-diesel are ranked as most preferred scenarios. Fossil fuels are most preferred by *vehicle manufacturers (figure 12)* because of the easy accessibility to the vehicle market and the low (additional) investment and development costs. Nevertheless, focussing on fossil fuels will not be effective in attaining a 'green image'. Biogas is the most preferred fuel to obtain a green label, but this gaseous fuel is clearly not an option in view of the other goals. For *end users (figure 13)*, *fossil fuels* and *biodiesel* (through B10) are the preferred options given that these fuels have no impact on the total cost of ownership of the vehicle, technical compatibility, user friendliness and safety. Fossil fuels are more favoured than biodiesel with respect to the knowledge of the fuel ('transparency'). On the other hand, to reach the objective 'green image', there is a complete different prioritization of scenarios than for the other goals. Here, biogas and bio-ethanol are the most effective ones. Biogas is the most effective option for *government (figure 14)* as it positively contributes to ecological criteria such as 'greenhouse gas balance', 'local air quality' and 'reduction of oil dependency'. Compared to the other biofuel scenarios, it also has a small impact on 'governmental budget' and 'food prices' and adds to employment creating 'economic growth'. It however scores less on the compliance with EU standards, a criterion where bio-diesel (2nd preferred option) has the best performance. For *NGOs and North-South organizations (figure 15)*, bio-ethanol is the most important biofuel scenario as it greatly adds to their most important criterion 'ecological impact of the production chain', which is measured by ecosystem quality, water use and GHG savings and to the criterion 'fair prices for local farmers'.

Step 7: Implementation

This is the final step of the MAMCA, after the policy maker has decided on which alternative to implement. The information on the point of view of each stakeholder, gathered from the previous steps, helps tremendously in identifying implementation pathways and additional policy measures to facilitate the introduction of the chosen alternative (see section 4). In this step, it is possible to include new alternatives or modify existing ones as more insight into the advantages and disadvantages of a certain alternative for each stakeholder is generated. This would then create a feedback loop towards the beginning of the procedure.

5. POLICY IMPLICATIONS

Adequate policy measures are of vital importance to facilitate the introduction and development of biofuels (Faaij, 2006). The Belgian quota system combined with specific tax reductions has demonstrated that this system alone does not guarantee the market uptake of biofuels. Even if the assigned production quota of biodiesel and bio-ethanol would find entrance in the Belgian market, it would only replace maximum 4,2% (by energy) fossil fuels by biofuels in 2010, which is below the national target of 5,75% (by energy). The fuel mandate, issued by Belgian authorities in 2009, was an additional step to oblige fuel distributors in achieving 4% biofuels (in volume) in their total sales. Taking into account that 4% in volume corresponds to 3,7% (in energy) biodiesel and 2,7% (in energy) bio-ethanol, the obligation will not be sufficient to reach the national 5,75% target (EC, 2003a) and as a consequence the 10% target in 2020 (EC, 2008).
The MAMCA approach revealed that increased general blending of bio-diesel (B10), combined with high ethanol blends (E85) in certain (niche) markets is the most effective option to reach high biofuel shares on the Belgium market. This strategy is also supported by Bomb et al. (2007) stating that rather than only producing low-level blends for conventional vehicles, the focus should also be on high blends in niche markets such as bus fleets for public transport, truck operators and agricultural vehicles. The MAMCA insight into the different stakeholder groups however highlighted barriers which need to be tackled in order to get a successful uptake of these fuels on the Belgian market. For *biofuels producers*, the MAMCA revealed that bio-diesel and ethanol are more costly to produce than fossil fuels. Moreover, the Belgian quota system will disappear after 2013, which means that the competition of cheap feedstock from international markets (e.g. from Brazil, Argentina and USA) will increase, disfavoring investments and job creation on the national level. A possible support for biofuel producers could consist of a continuation (and possibly an enlargement) of the *quota system* with tax reductions combined with incentives such as *direct subsidies*, proportional to the amount of biofuels produced (Pelkmans et al., 2009). Additionally, in order to enhance sustainable biofuel production, *incentives* can be given only to manufacturers processing feedstock for non-food use (Pelkmans et al., 2006). Although 4 bio-diesel and 3 ethanol plants are currently operational in Belgium, the availability of these fuels at the filling stations is currently very limited. Even with the fuel mandate, biofuel production capacities

will remain underused as *fuel distributors* are not inclined to go beyond this mandated target. Next to the quota system and fuel mandate, a sufficient *tax reduction* to cover the extra biofuel costs will probably be necessary to encourage fuel suppliers in introducing a larger share of biofuels in their total sales. Moreover, in order to reach the 10% target by 2020, the focus should also be on high blends (e.g. E85) to be offered by private pumps for captive fleets and/or public pumps. This requires not only an adaptation of the *fuel quality standards* for high biofuel blends by the CEN, but also a close collaboration with *vehicle manufacturers* to deliver biofuel compatible vehicles. Countries with own car industries such as Germany and Sweden have greater success in the introduction of high blends because of their close cooperation with local *vehicle manufacturers* such as Volkswagen and DaimlerChrysler in Germany and Scania, Saab and Volvo in Sweden. Saab, Volvo, Ford, PSA-group, GM and Renault are ready to offer FFVs (for E85) on the Belgian market, but are requiring a uniform *European fuel standard* and access to the market. To increase market demand, an *authorization to sell high blends* for fuel distributors is required together with incentives such as *fuel tax reductions* or *user advantages* to enhance the attractiveness of biofuels for end users. For *end users*, the total cost of ownership revealed that the purchase and use of biofuel compatible cars is still more expensive than conventional fossil fuel vehicles. *Fuel tax reduction* would be a possible instrument to counterbalance the higher production cost of biofuels and ensure the price competitiveness of biofuels (Bomb et al., 2007). User advantages such as *free parking* or *reduction of circulation taxes* for biofuel vehicles could also compensate the additional costs. Moreover, the compatibility, availability and user friendliness of vehicles and fuels should be ensured. Systems to encourage the availability of fuels could include *subsidies* for filling stations and *mandates* to *fuel distributors* to offer at least one renewable fuel. *Demonstration and research projects* could also enlarge the visibility and illustrate the user friendliness of biofuel compatible vehicles. Other possibilities include *procurement methods* such as *public green procurement* (number of clean vehicles to be included in public sector fleets), *common procurement* (a large number of users purchasing clean vehicles to achieve economies of scale and reduce costs) or *leadership by example* (use by other vehicle users, governmental fleets or public transport fleets) (Pelkmans et al., 2006; Pelkmans et al., 2009). The MAMCA also illustrated the lack of transparency with respect to the knowledge and information on biofuels. *Awareness building campaigns*, together with the creation of objective websites, brochures and a biomass observatory could contribute to a better knowledge and understanding. For *government* and *NGOs*, the MAMCA showed that the sustainability of biofuel production should be ensured. The new Renewable Energy Directive (EC, 2009) already contains *sustainability criteria* such as the fact that biofuels shall not be made from raw materials obtained especially from land with recognized high biodiversity value, from forests, from areas designated for nature protection, from highly bio-diverse grassland etc. (Art. 17 of 2009/28/EG). European Member States still have time until the end of 2010 to implement these sustainability requirements into national law. For NGOs, additional sustainability requirements might be vital as indirect land use changes and social effects are not covered yet by Directive 2009/28/EG (IST, 2009).

6. CONCLUSIONS

In this paper, a framework has been proposed to help decision makers identifying their long-term biofuel strategy by taking the opinions of the involved stakeholders into consideration. This Multi-Actor Multi-Criteria Analysis (MAMCA) (Macharis, 2000) has been applied in the case of Belgium and has subjected several scenarios (fossil fuels, bio-diesel, ethanol, biogas and biomass-to-liquid) to evaluation by different actors of the biofuel supply chain (feedstock producers, biofuel producers, biofuel distributors, end users, vehicle manufacturers, government, NGOs and North-South organizations). The MAMCA showed that bio-diesel (through B10) and ethanol (through E85) are the most preferred scenarios. A combination of these scenarios will be effective to reach high biofuel shares on the Belgian market. To reach the European target of 10% biofuels by 2020, additional actions might become necessary such as the introduction of the 2^{nd} generation biofuels. The MAMCA revealed that BTL is also highly supported by the biofuel supply chain, but still copes with practical problems to be resolved before it becomes reliable and commercially available. On the long-term, the focus should be on a combined 1^{st} and 2^{nd} generation biofuel strategy in which experiences from using 1^{st} generation biofuels will be transmitted to stimulate the development of 2^{nd} generation biofuels**.** Overall, a successful implementation of biofuels can only take place in accordance with a national regulatory and economical framework for providing long-term signals to all actors of the supply chain.

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