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Integrated Evaluation of Biofuel Production Options in Agriculture: An Exploration of Sustainable Policy Scenarios

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ABSTRACT

This paper addresses the future potential of biofuel production in agriculture, with a particular view to its implementation in agriculture in Europe. After a brief account of recent developments, an exploratory meta-analysis is presented in order to assess the effectiveness of biofuel production from the perspective of several relevant policy y criteria. Next, various scenarios are outlined and evaluated by means of a multi-criteria analysis, so as to judge the feasibility of various biofuel production options. The paper concludes with some policy lessons.

1. INTRODUCTION

In recent years, we have observed a significant shift in the political interest in – and consensus towards – an energy future characterized by a substantially larger renewable energy share, both in Europe and also in Italy. In particular, interest in biofuels has grown rapidly in recent years in response to the rising cost of fossil fuels and the increasing public concern about environmental issues, e.g. in the transport sector, with regard to climate change (EEA, 2009). The necessary reduction in the emissions of greenhouse gases (GHGs) addressed in the Kyoto Protocol and by Directive 2009/28/EC (RED) of the European Commission provides for the use of biofuels instead of fossil fuels, one of the major causes of GHG emissions. Among the biofuels sources, biodiesel is now the most available source of renewable energy for transport in the European market. According to European policy the biodiesel was one of the promising biofuels that can satisfy the principles of sustainability currently heavily debated (Finco et al.,2010). It is noteworthy that over the past decade the biofuel industry has experienced a period of extraordinary growth, fuelled by a combination of rising oil prices, ambitious blending mandates, tax exemptions and import protection. The current EU market leader is Germany, followed by France and Italy. However, the increased price of vegetable oil and the economic crisis have exerted a negative impact on biodiesel production. Furthermore, the overall environmental effect of biofuels and the potential land-use competition with food production have triggered a negative public image of biofuels (Takahashi and Nijkamp, 2010).

In order to assess the environmental performance of the production of biodiesel versus fossil fuels, the paper aims to identify environmental criteria in order to evaluate the impact of the entire biodiesel production chain, from farm to final consumer. The main raw materials considered here are: rapeseed, sunflower and soybean, and palm oil (mostly from Malaysia) was also taken into consideration.

The present study begins with a comparative survey, followed by an exploratory meta-analysis of scientific and technical reports emerging from international research efforts that highlight the most important environmental criteria for various types of biomass used in biodiesel production chain. The information on the literature from our comparative meta-analysis enabled the design and implementation of a multicriteria methodology to support the choices of public policy aimed at obtaining a sustainable development strategy.

Clearly, the commercial biofuel industry requires the explicit consideration of one or more criteria in addition to environmental criteria, i.e. concerning efficiency and market viability. Consequently, in our study, the economic criterion to be included in our analysis is the commodity price. Next, various relevant multicriteria scenarios will be employed to highlight a dichotomous policy result depending on ecological vs. economic arguments, and therefore, on the question of how society evaluates overriding environmental criteria compared with the economic indicator.

2. BIOFUEL POLICY

The European Union aims to increase the share of renewable energy in its total energy consumption package in order to reduce GHGs and make the economy more CO_2-neutral. This policy is further motivated by a desire to reduce dependency on fossil fuel imports and to stimulate rural development and the agricultural sector (Banse et al., 2010). Several vehicles of agricultural policies such as the Common Agricultural Policy (CAP) in Europe, as well as of energy policies, directly and indirectly stimulate the production of renewable energy from the agricultural sector. At the EU level, three political decisions have played a fundamental role in the expansion of biofuels: the CAP; the 2003 Directive (2003/30/CE); and the more recent Directive of 2009 (2009/28/CE).

The EU Renewable Energy Directive (RED, Dir. 2009/28/EC), on the promotion of the use of energy from renewable sources, is a powerful measure at the heart of European energy and climate policy. It sets out two targets aimed at the promotion of renewable energy. The first requires the delivery of 20 per cent of total energy from renewable sources by 2020, with the level of effort differentiated across the Member States. The second specifically promotes the use of energy from renewable sources within the transport sector, requiring 10 per cent of all transport fuels to originate from renewable sources by 2020 across every Member State. Moreover, the RED introduces also quantitative sustainability criteria(Art.17-18-19-Annexe V[1])(: a minimum threshold of GHG savings has to be achieved, while biofuel must provide for at least 35 per cent carbon emission savings compared with fossil fuels in 2010; this level will have to rise to 45 per cent by 2013 and to 50 per cent by 2017, taking into consideration that some types of land are unfit to grow biofuel crops, and that social standards also have to be met Demirbas, 2009). In particular, biofuels may not be produced from raw materials obtained from land with a high biodiversity value, e.g. primary forest and other wooded land, highly biodiverse grassland, and from land with high carbon stock, e.g. peatland and wetlands.

Therefore, the ambitious targets set for biofuel market shares require the implementation of effective and efficient policy instruments. This will require complementary instruments, such as subsidies for production facilities, use of incentives, or feedstock subsidies. The need for suitable policy instruments also becomes obvious with regard to the aim of large market volumes. Clearly, biofuels are currently commercially uncompetitive with fossil fuels (petrol and diesel) in Europe. However, they might become uncompetitive, once their external benefits to society: namely, the CO_2 emission reduction, security of energy supply, and rural development, are materialized.

[1] Art.19, including Annex V, explains the calculation of impact of biofuels on GHG emissions.

3. AN EXPLORATORY META-ANALYSIS

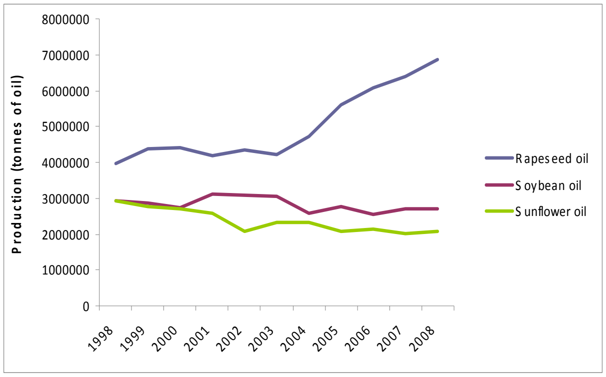
In the literature worldwide, we find several studies dealing with the potential of biofuel. For the assessment of the environmental impacts of biofuel resulting from their use – and in order to check the compliance with sustainability criteria – several studies have been undertaken which take into account the different phases of the life cycle of biofuels. In order to synthesize the resulting information provided by a broad range of scientific literature, an exploratory comparative meta-analysis was carried out (for details on meta-analysis, see Nijkamp et al., 1997). Meta-analysis, in general, aims to draw quantitative hypothesis inferences from a set of rather similar modelling efforts on statistical effect studies on the same phenomenon. In our case, we will not provide an explanatory framework, but only an averaging exploratory overview.

The meta-analytic approach undertaken by us considered 32 international technical and scientific studies (See Annex 1). An exploratory comparison of all these studies revealed that the most interesting environmental aspects to compare, for the valuation of biodiesel impacts, appear to be:

1. Emissions of GHGs in the production of biodiesel versus fossil fuels;
2. Energy balance of biodiesel production, processing and distribution;
3. Land-use change (direct and indirect).

The choice of these criteria can be justified as follows. Regarding the first criterion, it seems plausible to consider the savings in GHG emissions, because these (especially CO_2, N_2O and CH_4) are the major factors that influence the average temperature on earth. Regarding the second criterion, it is reasonable to focus on the positive energy balance of biodiesel, because it is of critical importance to look for an alternative source of renewable energy that can replace fossil fuels and can improve environmental performance (De Vries et al., 2010; Lechon et al., 2009; Kim and Dale, 2005). Finally, we also address land-use change, as the extensive land-use change necessary for biodiesel production (such as deforestation or conversion of pastures into land-used for energy) involves the loss of biodiversity, the reduction of carbon stocks, and the reduction of land for food (Hellmann and Verburg, 2010). The land-use change can be direct or indirect. Direct land-use change occurs when additional cropland is made available through the conversion of native ecosystems such as peat lands, forests and grasslands, as well as by returning fallow or abandoned croplands into production. Indirect land-use change can occur when land currently cropped for non-energy production is diverted for biofuel feedstock cultivation. The diverted crops must then be compensated for by converting other natural land, usually native systems (Ravindranath et al., 2009).

Regarding the choice of biodiesel as compared with fossil fuels, it is plausible to choose the biodiesel derived from vegetable oils, particularly rape, sunflower, soybean, and palm oil. The choice of biodiesel from vegetable oils is derived from the consideration that these oils are much more common in current oil markets[2]. These raw materials are chosen because these materials (rapeseed oil, sunflower oil and soybean oil) are the three most produced vegetable oils in Europe (Figure 1).



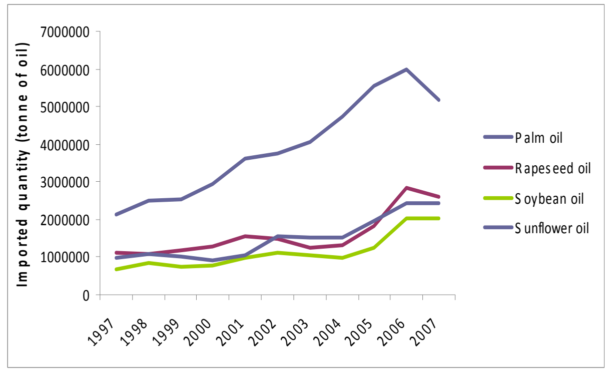


Figure 1: European production of vegetable oils from 1998 to 2008 **Figure 2: Quantity of vegetable oils imported in the EU from 1997 to 2007**

Source: FAOSTAT 2010

Finally, it is also plausible to consider palm oil from Malaysia, as this is, relatively, the most imported vegetable oil in Europe for the future production of biodiesel. Clearly, palm oil will enter the future competition (and comparison) with rapeseed, sunflower and soybean (Figure 2).

The choice of the criteria listed above has enabled the selection of studies on these issues. On the basis of the first criterion, we were able to identify studies that:

- Provide a percentage improvement of total GHG emissions of biodiesel compared with diesel during the steps of production, processing, and transfer to the distribution network, without considering the land-use change;
- Consider all four reference oils (rape, sunflower, palm and soybean) or at least three of these oils;
- Provide data obtained using similar methodologies, or provide values at least for the same stages of the life cycle.

On the basis of these characteristics, six studies were finally selected for our comparative analysis of biofuel production.

For the second criterion, the selected studies met the following conditions:

- Consider the energy aspects of all four types of biodiesel considered (rapeseed, sunflower, soybean and palm);
- Provide the ratio between the energy generated during the use of biodiesel in road transport and the energy utilized during production, processing and transportation of the biodiesel (energy efficiency).

[2] In addition to vegetable oils trere are oils from non vegetable origin, in particular animal fats, but they are not allowed in some European countries, including Italy.

The selected studies do not provide a comparison between the energy performance of fossil fuels and biodiesel, because all these studies have shown that biodiesel offers the best performance. So it is important to compare the energy balance of different types of biodiesel to see which of them has the best output/input ratio. The number of studies ultimately considered for further comparison was seven.

Finally, two studies were selected for the evaluation of direct land-use change, while for indirect land-use change only one study was considered.

The choice of each of the aforementioned groups of studies is now summarized in a set of survey tables that can provide the final information for an exploratory meta-analysis. For each criterion mentioned, a table was created showing the number of studies that provide the data of interest and the values for each type of biodiesel covered in our meta-analysis, including the final average amount.

Table 1 shows data on the first criterion, viz. saving greenhouse gases (GHGs) emissions in the production of biodiesel versus diesel. All data are expressed in terms of the percentage improvement of GHGs from biodiesel compared with those from diesel.

Table 1 : Improvement in GHG emissions of biodiesel vs diesel (in percentages)

STUDY	ENERGY CROP			
	Rape	Sunflowers	Palm	Soy
N° 10	37	–	45	37
N° 11	38	51	56	31
N° 12	48	–	70	62
N° 19	46	–	69	60
N° 23	45	58	62	40
N° 32	25	–	55	20
Average	***40***	***55***	***60***	***42***

Regarding the second criterion, the results are shown in Table 2.

Table 2: Ratio between energy supplied and fossil energy used (output/input)

STUDY	ENERGY CROP			
	Rape	Sunflowers	Palm	Soy
N° 1	2.4	2.3	–	–
N° 6	2.4	–	9.1	2.6
N° 10	2.5	–	9	1.9
N° 24	2.5	2.5	–	–
N° 27	3.2	2.8	–	–
N° 28	1	1.2	–	–
N° 31	1.3	1.9	–	3.3
Average	***2.5***	***2.4***	***9.1***	***2.3***

Regarding the direct change of land-use, the data and averages are given in Table 3. Values are expressed as a percentage improvement of GHG emissions from biofuels compared with those from diesel. Negative values indicate increase of emissions.

Table 3: GHG emissions avoided by biodiesel compared with diesel

STUDY	ENERGY CROP			
	Rape	Sunflowers	Palm	Soy
N° 12	2	17	-71	4
N° 32	-18	-3	-192	-16
Average	***-8***	***7***	***-132***	***-6***

The highest negative value for the palm oil indicates emissions due to substitution of peat in Malaysia. As for indirect land-use change, the data and averages are given in Table 4. The values are again expressed as the percentage improvement of biodiesel's GHG emissions compared with those from diesel, while negative values indicate an increase of emissions.

Table 4: GHG emissions avoided by biodiesel compared with diesel due to indirect land-use change

STUDY	ENERGY CROP			
	Rape	Sunflowers	Palm	Soy
N° 32	-45	-30	26	-43
Average	***-45***	***-30***	***26***	***-43***

4. MULTICRITERIA ANALYSIS

The comparative meta-analytic information from the previous tables allows the implementation of a multicriteria methodology to identify and support the choices of public policy aimed at obtaining a sustainable development process (Falcone et al., 2009; Nijkamp and van Delft, 1977; Nijkamp et al., 1989; Rehman and Romero, 1993; Saaty, 1980; Nijkamp and Beinat, 1998). In fact, the multicriteria analysis in relation to our meta-analysis results then allows us to identify the best alternative among the various types of biomass strategies used according to the principles of sustainability expressed by current EU policy (Hellmann and Verburg, 2010).

The multicriteria analysis in our study – based on the so-called Regime method (see Nijkamp et al., 1991) – was performed using the software "Definite 3.1" (Janssen, 1992). The objective was to identify among the different types of biomass used (rape, sunflower, palm, and soy) the best alternative in different scenarios from both an environmental and an economic perspective. The alternatives considered were identified on the basis of the different materials used in biodiesel production highlighted in the meta-analysis. The criteria chosen to perform the multicriteria analysis are the same as those considered in the meta-analysis (GHGs, energy balance, and land-use change). Therefore, a summary table (Table 5) was created to represent our meta-analysis results, which shows the average values for each criterion chosen for the different alternatives.

Table 5: Evaluation matrix for multi-criteria analysis

ALTERNATIVE	CRITERIA			
	GHGs %	OUTPUT/INPUT MJ/MJ	LAND-USE CHANGE (direct) %	LAND-USE CHANGE (indirect) %
Rape	40	2.5	-8.0	-45
Sunflowers	55	2.4	7.0	-30
Palm	60	9.1	-132.0	26
Soy	42	2.3	-6.0	-43

After the design and quantification of the evaluation matrix, the data entered in the matrix were standardized per column. The method used for the first two criteria is defined as 'maximum standardization', while the land-use change criteria (both direct and indirect), the method used is called 'goals standardization'.

The assignment of weights given to the relevant criteria in the multi-criteria analysis depends on the type of evaluation to be performed. They will be supported and derived by means of various policy scenarios in which different weights will be given to the different criteria.

- ***Scenario 1*: equal environmental weight system**

In the first case of our multicriteria study, an equal weight was given to all environmental criteria, because they were considered of equal importance in relation to their environmental impact.

- ***Scenario 2*: weight system based on Delphi method with policymakers**

The second case study involves the use of different weights for each criterion used. The choice of the priorities for different criteria was made by using a Delphi method. To this end, a survey was held among policymakers of the Marche region, in particular, those of the Agriculture Service and of the Environment and Landscape Service of the region. The aim of the survey was to obtain the opinion of policymakers to identify an appropriate weights system.

- ***Scenario 3*: compound weight system (environmental + economic criteria**

In order to consider not only aspects of environmental sustainability, but also the economic criterion of the biodiesel entrepreneur, an economic indicator is included as well. The commercial biofuel industry also requires the consideration of one or more criteria in addition to environmental criteria, viz. concerning efficiency and market viability. As mentioned above, in our study the economic criterion included in our analysis is the commodity price. In particular, our multicriteria analysis will consider only the price reported for the month of May 2010, expressed in €/tonne by Rotterdam commodities exchange, extracted from the palm oil website (see the new extended evaluation matrix in Table 6). The weights are assigned by considering the economic profit criterion as the most appropriate one. We assume that, in this case, land-use change is has lowest weight. Then the energy balance and GHG emissions can be listed, in order of importance. Table 6 will be used as the central evaluation matrix for our multi-criteria analysis.

Table 6: Evaluation matrix for multi-criteria analysis

ALTERNATIVE	CRITERI				
	GHG %	OUTPUT/INPUT MJ/MJ	LAND-USE CHANGE (direct) %	LAND-USE CHANGE (indirect) %	PRICE €/tonne
Rape	40	2.5	-8.0	-45	703
Sunflowers	55	2.4	7.0	-30	897
Palm	60	9.1	-132.0	26	632
Soy	42	2.3	-6.0	-43	678

5. RESULTS OF MULTI-CRITERIA ANALYSIS

The results from our multi-criteria analysis will now be represented in a graphic form, while a numerical analysis allows us to draw clear conclusions.

- **Scenario 1**

This scenario is based on zero weights for the price criterion and equal weights for all others. The analysis of this first case shows that the best environmental and energy package is provided by biodiesel from palm oil (Figure 3).

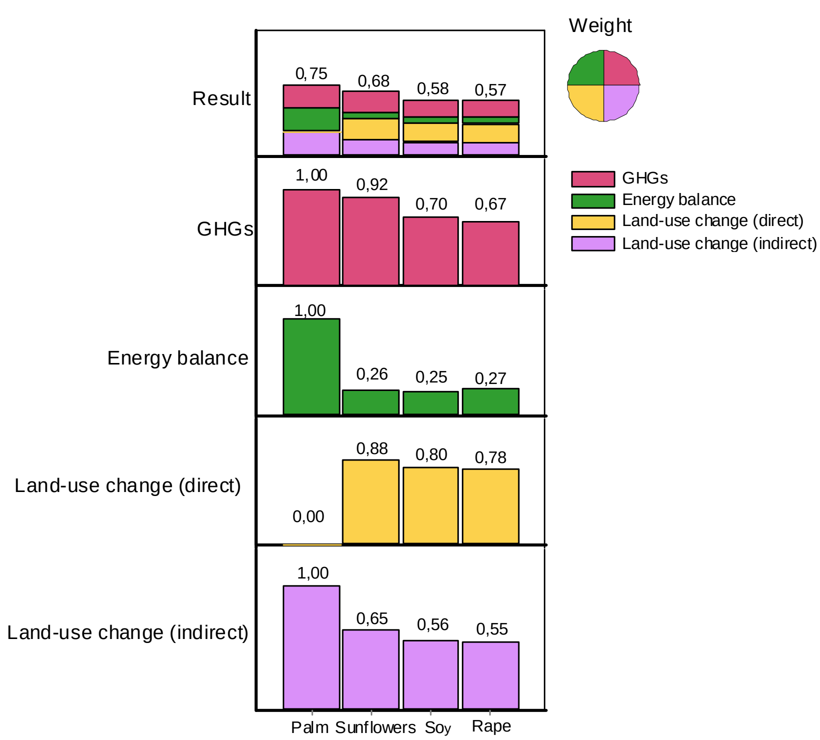


Figure 3: Results of Scenario 1

This type of fuel, in fact, recorded the best performance for three criteria (GHGs, energy balance and indirect land-use change). Only with regard to direct land-use change, its value is much lower than for other biofuels. Biodiesel produced from rapeseed, sunflowers and soybean shows final results that are quite similar. Biodiesel from sunflowers is what comes closest to the benefits of palm oil, and it provides the best results as regards the direct change of land-use.

- **Scenario 2**

The second case was conducted by assigning various weights to different criteria on the basis of the results of a survey among policymakers in the Marche region. We underline that the policymakers appear to attach the highest importance to direct and indirect land-use change as compared to other criteria. The most interesting result in this case (see Figure 4) is the best performance of sunflower oil compared to other energy sources, particularly with respect to palm oil. That is because land-use change, in this case, assumes a much higher value than the other two criteria. The rape and soybean oil produces an environmental performance similar to sunflower oil, even though their energy balance is slightly better. Among these two, the soybean oil is the raw material that provides a better environmental performance, although the differences are quite marginal. The soy biodiesel has, in fact, a better performance for both land-use change and the reduction in GHG emissions.

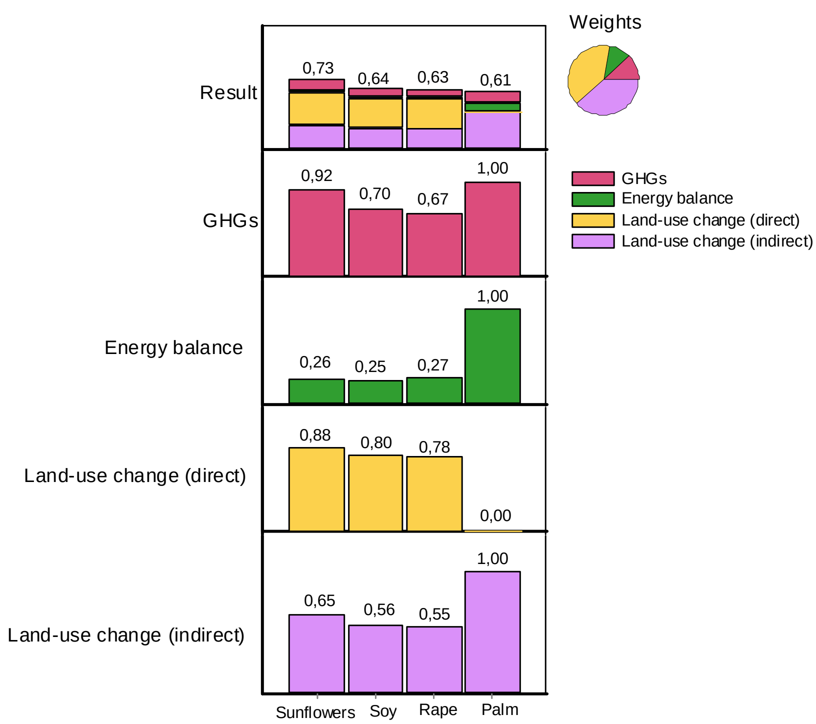


Figure 4: Results of Scenario 2

- **Scenario 3**

In the last case, based on a compound weight system of environmental a and economic criteria, the weights were assigned so as to give a greater importance to economic aspects than to environmental components. In particular, in a ranking exercise of this policy scenario, a maximum score was assigned to the price criterion, followed by the energy balance and GHGs (see Figure 5).

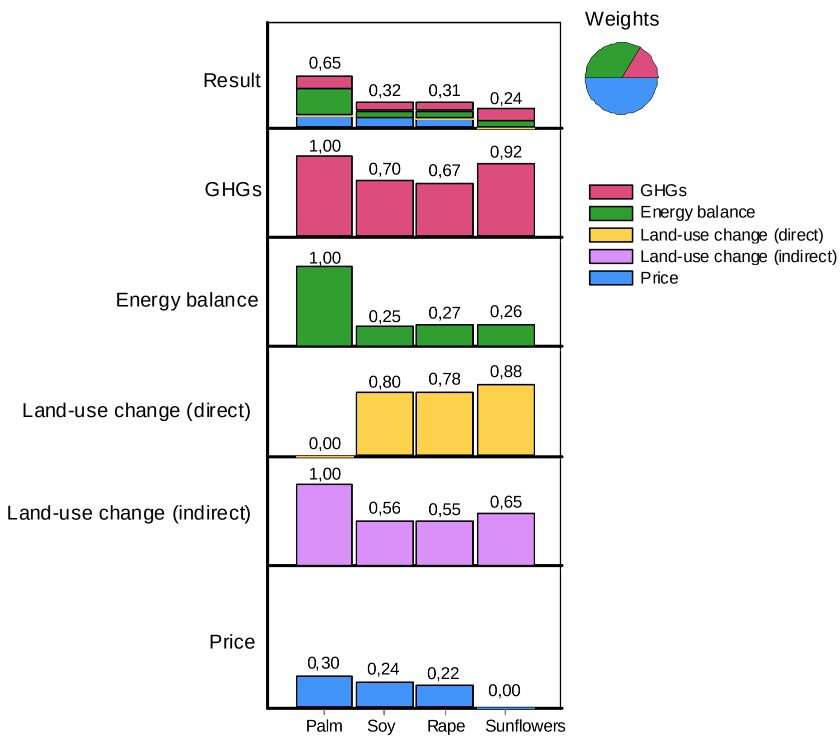


Figure 5: Results of Scenario 3

Regarding land-use change, this was assigned the lowest value, because this aspect is assumed not to becovered by the biofuel entrepreneur. The result of this scenario (Figure 5) identifies biodiesel from palm oil as the best alternative, because it has the best performance for most of the criteria taken into account. In this case, land-use change (the criterion for which palm oil has the worst performance) is not considered. Biodiesel from sunflower oil, however, is the least preferred alternative, because it has the worst performance on the price criterion, that i.e. it is the most expensive option. Biodiesel from rapeseed and soybeans appear to be less preferable to biodiesel from palm because of their inferior results on the most important criteria. They are however, more desirable than sunflowers, because in this scenario they have of the highest scores for the primary criterion (i.e., the economic criterion).

6. CONCLUSIONS

The reduction of greenhouse gas emissions embodied in the Kyoto Protocol and in the EU Directive 2009/28/EC highlights the importance of biofuels (and, in particular, their use in the transport sectorone of the major causes of GHG emissions). Among the agro-energy sources, biodiesel is now the most available source of renewable energy in the European market; biofuel can satisfy the principles of sustainability in the current climate debate. The meta-analytic approach in our study, which considered 32 international technical and scientific reports, revealed that the use of biodiesel allows an emission reduction of CO_2 relative to diesel (according to EU Directive 2009/28/EC), and a positive energy balance of biodiesel in the production chain. The biodiesel production chain will increase the environmental impact, because there is a land-use change inherent in cultivating energy crops at the expense of forests or natural areas.

The multicriteria analysis allowed us to define the best alternative between different agricultural raw materials according to sustainable development policy which is underlined in European policy. The policy-makers appear to attach great importance to environmental sustainability criteria. In fact, from an environmental perspective Scenario 2 shows that the best solution at European level is biodiesel production based on sunflower oil. This solution would be very interesting for Europe and especially for Italy (South/Central), because this region is particularly suited for the production of this crop.

The biodiesel production from sunflower oil may also lead to a series of positive externalities, such as a significant contribution to self-sufficiency in energy and the enhancement of agricultural production with minimum environmental impacts due to the cultivation of fallow or abandoned land. It should be noted that Scenario 3 shows the point of view of a biodiesel economy that wants to maximize its profits without a high priority to environmental conditions. In this case, palm oil from Malaysia is the best alternative. Thus, the final results to be translated into policy strategies call for an articulation of environmental and economic growth priorities.

It is therefore, clear that political decisions will have a crucial role to play. These are decisive whether to push sustainable development by internalizing environmental externalities, or by letting the market decide according to a private optimum versus a social optimum perspective.

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ANNEX 1: Studies considered in the meta-analysis tables

Title	Author	Years
1) Energia dalle biomasse. Le tecnologie, i vantaggi per i processi produttivi, i valori economici e ambientali	Gelleti et al.	2006
2) A comprehensive analysis of biodiesel impacts on exhaust emissions. Draft technical report	US-EPA (United States - Environmental Protection Agency)	2002
3) Towards sustainable production and use of resources: assessing biofuels	UNEP-International panel for sustainable resource management (United Nations Environment Programme)	2009
4) Saskatoon biobus – Phase II. Final Research report	Munshaw and Hertz	2006
5) Biobus: biodiesel demonstration and assessment with the Socièté de Transport de Montrèal (STM). Final report	BIOBUS Project Committee Members	2003
6) Crops for biofuel: current status and prospects for the future	Connor and Hernandez	2009
7) Energy balance and greenhouse gas emissions of biofuels from a life cycle perspective	Menichetti and Otto	2009
8) Greenhouse gas implications of land-use and land conversion to biofuel crops	Ravindranath	2009
9) Air quality issues associated with biofuel production and use	Hess et al.	2009
10) Introduction: biofuels and the environment in the 21st century	Howarth et al.	2009
11) Germany's biodiesel sector has now to document its sustainability	UFOP	2010

12) Biodiesel at a dead end!?	UFOP	2009
13) Final report. Biodiesel initiatives in Germany	Gärtner and Reinhardt	2005
14) The Vermont biodiesel project. Building demand in the biofuels sector	Delhagen	2006
15) Prime valutazioni sull'impatto delle produzioni agroenergetiche in Sicilia	Bracco et al.	2008
16) Comparison of shell middle distillate, premium diesel fuel and fossil diesel fuel with rapeseed oil methyl ester	Munack et al.	2006
17) Proposal for biodiesel production facility	Azman	2001
18) Cost and life-cycle analysis of biofuels	Brauer et al.	2008
19) UFOP information on paradigm shift in biofuel policies: from volume quotas to a greenhouse gas avoidance quota and the effects on biofuels	Henke and Schmitz	2008
20) Helping create sustainable agriculture in Snohomish and North King Counties	Wolfkill Feed & Fertilizer Inc.	2006
21) Freight transportation case studies. Hbc's biodiesel pilot projec	Hudson's Bay Company (Hbc)	2006
22) German biomass sustainability ordinance. Commentary paper to the draft dated December 5th, 2007	UFOP	2008
23) Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009	Parliament and Council	2009

24) Rapporto sul biodiesel. Prospettive nel breve termine dei combustibili rinnovabili derivate da oleaginose nel quadro delle nuove politiche agricole e degli impegni assunti dall'Italia a Kyoto	Riva et al.	1999
25) Riduzione dell'impatto ambientale dei motori diesel	CTI (Comitato Termotecnico Italiano)-Energia e Ambiente.	2002
26) The Gallagher Review of the indirect effects of biofuels production	Gallagher	2008
27) Colture energetiche legnose, nuove opportunità	Scaravonati	2008
28) Il ruolo dell'agricoltura e dell'industria sementiera per l'ottimizzazione della filiera	Venturi	2009
29) Life cycle analysis of biofuels under different environmental aspects	Kaltschmit et al.	1997
30) Evaluation of the comparative energy, global warming and socio-economic costs and benefits of biodiesel	Mortimer et al.	2003
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