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Biofuel market and carbon modeling to evaluate French biofuel policy

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Abstract [1]

In order to comply with European objectives, France has set up an ambitious biofuel plan. This plan is evaluated considering two criteria: tax exemption need and GHG emission savings. An economic marginal analysis and a life cycle assessment (LCA) are provided using a coupling procedure between a partial agro-industrial equilibrium model and a refining optimization model. Thus, we are able to determine the minimum tax exemption needed to place on the market a targeted quantity of biofuel by deducing the agro-industrial marginal cost of biofuel production to the biofuel refining long-run marginal revenue. In parallel, a biofuels LCA is carried out using model outputs. Such a method avoid common allocation problems between joint products. The French biofuel plan is evaluated for 2008, 2010 and 2012 using prospective scenarios. Results suggest that biofuel competitiveness depends on crude oil prices and petroleum products demands. Consequently, biofuel tax exemption does not always appear to be necessary. LCA results show that biofuels production and use, from «seed to wheel», would facilitate the French Government's to compliance with its «Plan Climat» objectives by reducing up to 5% GHG emissions in the French road transport sector by 2010.

Key words: Biofuels; Linear programming; Policy analysis

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[1] Expended version of a talk presented at the 29th IAEE Conference in Potsdam, Germany, June 2006 (see Bernard et al., 2006).

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1. INTRODUCTION

Transport is an issue of great concern to European countries for three main reasons. First, transport is almost totally dependent on oil and it accounts 67% of the final European oil demand. Second, strong inertia characterizes transports. The transport sector is the only sector to have known a steady growth since 1990 and by 2010 the increase in fossil fuel demand is expected to reach +16% for cars, +90% for planes and +50% for trucks (E.C., 2002). Third, transport is responsible for 21% of all greenhouse gases (GHG) emitted in Europe. European countries aim at lowering their oil dependence because oil prices are high and volatility makes countries vulnerable to a possible oil shock. Consequently, the European Commission (E.C.) has decided to secure its energy supply by reducing its import bill in diversifying its energy sources and technologies. Europe thus needs to find alternative transportation fuels that have a low environmental impact and allow for a rapid and easy substitution. For this reason biofuels are considered in the short and middle term by the E.C. as one of the best candidates to replace traditional fuels for transport (E.C., 2004). Since biofuels are liquid fuels, they can indeed be used with no major difficulties by current distributing infrastructure and in car engines by blending them with fossil fuels. In addition, it has now been proven that biofuels, when they are produced in a rationale way, are efficient to reduce CO_2 emissions because they are produced from renewable sources (ADEME et al., 2002; EUCAR et al., 2006). To help in such a substitution, the E.C. launched a European-wide program to promote biofuel in accordance with Kyoto protocol commitments. This program fixes biofuel target rates for compulsory biofuel blending in fossil fuels from 2005 to 2015. Every European country has to comply with the E.C. objectives using voluntary involvements, eco-labels, pilot projects, fiscal and legislative measures, and its own potential to produce biofuels, i.e. «liquid or gaseous fuels for transport produced from biomass: biodegradable fraction of products, waste and residues from agriculture, forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste»(E.P&C, 2003).

As for France, the country studied in the present paper, the main potential comes from agriculture. France is the first agricultural producer in the EU and over the 25 last years, the agricultural sector has increased its production by 35%. With 30 million hectares of cultivable land, 55% of the territory is dedicated to agriculture and about 19 Mha are used for crop production. Over this area, 1,5 Mha of fallow land, i.e. land that cannot be used for food crop productions, allow biofuel crops cultivation. In France, two main biofuels have been developed from crops so far: vegetable oil methyl ester (VOME) and ethanol. VOME is mainly produced from rapeseed and is used in blend with diesel fuel whereas ethanol is made from sugar beet and wheat and is used in gasoline engines. These crops are already well-known by French farmers who are the leading European producers of them. Even if a great part of these crops are exported, competition for land use may arise as soon as biofuel crop production goes beyond the set aside land (see Ignaciuk et al., 2006; Treguer et al., 2005). Furthermore, land use and crop rotation will be disturbed because of the important need of oleic crops compared to sugar beet and cereals. Indeed, France faces a huge imbalance in fuel demand, which is much more oriented toward diesel than toward gasoline. As a consequence, and because refineries were initially gasoline oriented, French refiners are under pressure for their diesel production and need to import diesel mainly from Russia to meet the demand. Furthermore, as diesel and gasoline are joint products, refiners overproduce gasoline and need to export some to the United States. Biofuels allowing diesel substitution could probably release the pressure on diesel production but advantages for ethanol seem to be more limited. As biofuels are involved in several sectors, their development need to be coordinated. For this reason, the French government has set up a legislative and fiscal frame to promote biofuels with strong and ambitious biofuel production targets.

The main objective of the present paper is precisely to study the French biofuel program for 2008, 2010 and 2012 by jointly conducting a market and a life cycle analysis of biofuels. Indeed, insofar as we consider that firms make decisions based on profit maximization and that there is no penalty on GHG emissions, life cycle assessment (LCA) should not be dissociated to the economic analysis. For this purpose, a French partial agro-industrial equilibrium model is coupled to a French refining sectoral optimization model, both based on linear programming (LP). Using marginal analysis, this tool is able to determine the agents' technico-economic interest for biofuels through a systemic and integrated approach. For each year, an LCA is carried out to asses the reduction of GHG emissions thanks to biofuel use. The use of linear programming models in such an analysis avoids the problem of emission allocation between joint products we meet in LCA methodology. In parallel, we study the amount of tax exemption needed for biofuels production in order to reach the government biofuel blending targets considering three crude oil prices. Tax exemptions are intended to compensate for the price gap between biofuel price and the corresponding fossil fuel price. It is precisely this price gap the two models allow us to determine through linear programming dual prices. We then discuss biofuel competitiveness. On the basis of a clear view of the individual economic choices and pollutant emissions along the biofuel production chains, planners should be able to tune their policies. This paper provides a long-run analysis in 2008, 2010 and 2012 using prospective scenarios.

The innovative element of this methodology is the consideration of both biofuel supply and demand, along with environmental criteria such as reduction in GHG emissions when using biofuel in substitution for fossil fuels.

The paper is structured as follows. Section 2 describes the French biofuel production chains and promoting policies. Section 3 presents the agro-industrial and the refining model as well as the coupling methodology. Section 4 describes how GHG emissions are accounted for. Section 5 describes the prospective scenarios and the results of their evaluations. Section 6 provides some conclusions.

2. FRENCH CONTEXT FOR BIOFUEL DEVELOPMENT

2.1. French biofuels production chains

Sugar beet and wheat for ethanol and rapeseed for VOME are the main biofuel crops produced by French farmers. These crops then follow a two-stage process in industries that transform agricultural products into biofuels. Once the biofuels have been produced, they are blended with fossil engine fuels by refiners or distributors.

VOME is made from rapeseed (92% in quantity in 2003) and sunflower (8%) (ONIOL, 2004). After gathering and transport, crops are crushed in industries to produce vegetable oil. A co-product, cattle cake, is also obtained and often valorised in breed feeding. The produced oil can be used for both human consumption and chemical engineering purposes. When biofuels are produced, vegetable oil is chemically processed with methanol into VOME. This stage also produces glycerine which after purification can be valorised in cosmetics and pharmaceutical products. Afterwards, a refiner is allowed to blend up to 5% in volume of VOME with diesel engine fuel and up to 30% in captive fleet engines.

On the other hand, ethanol is produced by French farmers from sugar beets (78% in quantity in 2003), wheat (15%) or corn (7%)[2] . Sugar beets are bought by sugar industries in order to produce a sweet juice by diffusion. This sweet juice is generally used to produce sugar but it can also be used for alcohol production. As for wheat and corn, they are hydrolysed by enzymes or chemicals to obtain a fermentable mixture. This one is then fermented by yeasts and distilled to produce anhydrous ethanol. These stages coproduce sugar beet pulp and distilled dry grain solubles (DDGS) from wheat which are valorised in breed feeding. Refiners can then use bioethanol in two different ways: for direct blending up to 5% in volume or for ETBE production by chemical reaction with isobutylene. ETBE can then be blended with gasoline up to 15% in

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[2] While sugar beets represent 24% of the cultivated area of bioethanol crops, wheat represents 68% and corn 8%.

volume (ethanol : 7% in volume). Furthermore, since the beginning of year 2006, the E.C. has encouraged the use of E85 which is a blend of 85% of ethanol with 15% gasoline in dedicated engines. Nevertheless, this use remains marginal today.

Biofuel profitability is linked to co-products valorisation. As observed for glycerine, the more biofuel produced, the less profitable because of co-product market saturation. The price for glycerine has thus dropped from 1,300 $/T in 2003 to 125 $/T in 2006[3] . Consequently, stakes are high in the search for other co-product outlets.

2.2. French biofuels promoting policies

In France, ethanol and VOME market development is highly dependent on promoting policies because of the lack of cost competitiveness of biofuel technology compared with the fossil fuel technology. Policy measures in support of biofuel have been set up at each biofuel production level and biofuel blending targets have been scheduled.

At the upper level, the Common Agricultural Policy (CAP) reform of 1992 introduced a favourable context for biofuel development through the introduction of compulsory set-aside land. In this area, crops intended for human food production cannot be cultivated. It was initially planned to manage crop supply. Nevertheless, farmers are allowed to produce non food crops (including energy crops) on set-aside lands and benefit from a set-aside payment of about 63€/ha. The set-aside obligation was fixed at the rate of 10% of farms useful agricultural zone (AUZ) but it can be modified by the E.C[4]. Traditionally confined to set-aside lands, energetic crops will obviously have to go beyond this area of about 1.5 Mha to reach European objectives. What is more, since 2003 farmers have been able to take advantage of a special aid of 45€/ha for energy crops if they produce crops intended for biofuel production on arable land. This aid is limited to 1.5 million hectares for the whole of Europe.

At the halfway level, industrialists can benefit from an advantageous fiscal measure. After answering a European candidature call, an industrialist can receive tax exemption on fuel products from the French government. In fact, such industries receive an approval to produce a limited quantity of biofuels. In this way, the industries are sure to sell their biofuel productions to refiners who can benefit from tax exemption on the biofuel quantity used in substitution of taxed fossil fuels. In 2006, tax exemption amounts reach 33€/hl for ethanol used in direct blending or for ETBE production, and 25€/hl for VOME.

In addition to these measures, more ambitious biofuel incorporation objectives have been set by the French government at 5.75% in energetic content[5] for 2008, 7% in blend for 2010 and 10% for 2015. These targets take the shape of the tax rate of the general tax on pollutant activities (TGAP) applied both on gasoline and diesel sales figures. This tax can be exempted in due proportion to the rate of biofuel blended with fossil fuel in energy content up to the targeted rate. The formula could be written as follows:

$$TC = (TR - BR)Q_{EF}\,(P_{EF} + AT), \text{ with } BR = \frac{Q_{BF}}{Q_{EF}}, \text{ until } TR \geq BR$$

With TC: TGAP cost,
TR: TGAP rate,
BR: biofuel rate

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[3] Kingsman biodiesel report (22 march 2006)

[4] In 2004, it was fixed at 5% because of 2003 dryness.

[5] The energetic content is expressed in net calorific value (NCV), i.e., amount of heat released by complete combustion of a unit weight of fuel.

QBF : biofuel quantity,
QEF : engine fuel quantity,
PEF : engine fuel price.

For both ethanol with gasoline and VOME with diesel, for the refiner the TGAP cost represents the difference between TGAP rate reduced by the biofuel rate which is the quantity of biofuel proportioned with the corresponding engine fuel quantity. The remaining tax rate is applied to the engine fuel revenue corresponding to the quantity of engine fuel produced multiplied by its price added with some additional taxes (AT). Then if more biofuel is incorporated than the tax rate (BR>TR), no more tax exemption is given, but the whole TGAP is exempted.

In order to study possible biofuel market evolution and pollutant emission reductions due to biofuel use, a complete representation of biofuel production chains is necessary. The economic behaviour of farmers, industrialists and refiners have to be represented in order to study their economic interest in biofuels depending on the crude oil price as well as their GHG emissions. This approach was made possible by combining a French agro-industrial supply model with a French refining model[6] .

3. LINEAR PROGRAMMING MODELS DESCRIPTION

3.1. French agro-industrial equilibrium model

3.1.1. General description

The French agro-industrial equilibrium model (OSCAR[7]) is a partial equilibrium model based on linear programming. It is composed of a sequential multi-annual and regional agricultural supply model (MAORIE) combined with an industrial module (for further details on the agro-industrial model see Rozakis and Sourie, 2001). The objective function of the model is the maximization of joint profit for farmers and industrialists. Here farmers and industrialists constitute a complex with perfect coalition agents and the share of the internal surplus is not discussed.

On the one hand, the MAORIE agricultural supply model determines crop selection decisions by farmers considering crop margins, farming and supply constraints. It represents more than 80,000 crop producing farms based on a sample of 1,379 elementary models of farm. These elementary models are characterized by different AUZ and crop yields representing French agriculture according to the Farm Accountancy Data Network (RICA). Each farm belongs to a French region and to one of two agricultural types with different crop choices, «cereal» production oriented (56% of farms) and «sugar beet» production oriented (44%). On this basis, seventeen crops or land uses[8] are taken into account and differentiated according to: (1) the agricultural type; (2) the region of the farm where the crop is grown; (3) the preceding crop in cultural rotation; (4) the final use (human food or energy); (5) the growing area (inside or outside set-aside land). Furthermore, the MAORIE part of the OSCAR model is a sequential multi annual model from 2004 to 2012. The situation of a given year is based on the situation of the year before. Social and economic criteria, such as farming force, farmer ages, farmer fixed charges and gearing, farm size and stocking capacities, etc. For each farm, the age of the farmer and his gearing is calculated to orientate the development of the farm: continue its activity, make the farm available to other farmers or to other activities. Furthermore, CAP reforms and agronomic advancement in

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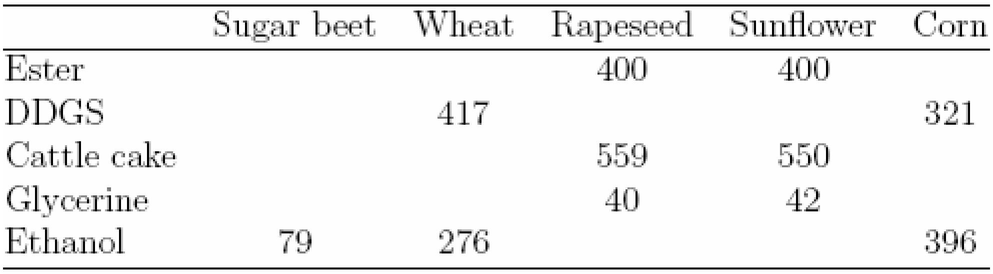
[6] Both models are written in GAMS code (Brooke et al., 1998).

[7] OSCAR: ‘Optimisation du Surplus économique des Carburants Agricoles Renouvelables’; model developed by the the Joint Research Unit in Public Economics, (INA-PG / INRA), Grignon.

[8] Wheat, hard wheat, sugar beet, rapeseed, potato, pea, sunflower, oats, soya bean, winter barley, barley, maize, sorghum, horse bean, linen, lucerne and fallow.

yields are taken into account for the 2004 to 2012 period. On the other hand, the industrial module is composed of global biofuel supply constraints for ethanol from wheat, sugar beets and VOME from rapeseed. Remaining marginal, biofuels produced from corn and sunflower are not taken into account in this paper. In addition, the following processing yields of biofuels and co-products are applied to crops into biofuel supply constraints (see table 1.)

Table 1: Agro-industrial processing yields in kg.t^{-1}



	Sugar beet	Wheat	Rapeseed	Sunflower	Corn
Ester			400	400	
DDGS		417			321
Cattle cake			559	550	
Glycerine			40	42	
Ethanol	79	276			396

3.1.2. Variables, parameters and equations

The variables of the OSCAR model are crop-cultivated areas per farm, biofuel and co-product productions. In this model 7,500 variables are associated with 6,800 constraints (Rozakis and Sourie, 2005). Main constraints concern land capacity, rotation of crops, fallow minimum and maximum requirements, crop and biofuel supplying, maximum land use by cereals, oilseeds, sugar beets, etc. The matrix of technical coefficients (yields), crop profits per hectare, biofuel prices, crop and biofuel subsidy amounts and also co-product prices are exogenous parameters.

The objective function maximizes farmers' profit with biofuel industrialists' profits. Aggregated farmers' profit is equal to each farm crop cultivation multiplied by profit per hectare. Industrial costs[9] are composed of: (1) crop collecting costs; (2) first industrial biofuels processing costs, i.e., oilseed grinding for cereals and sugar production costs for sugar beet; (3) second biofuel processing costs, i.e., unitary variable costs of processing vegetable oil in ester and fermentable juice in ethanol; (4) blending costs; (5) profits from co-products.

In addition, the OSCAR model makes it possible to determine the opportunity costs associated with biofuel raw materials and biofuels productions. A detailed description of raw material and biofuel opportunity costs determination and concepts are on the scope of the paper of Sourie (2002). Sourie defined the biofuel raw material opportunity cost as «the marginal cost of the least efficient producer so as to reach the demand». The biofuel opportunity cost is given by the biofuel raw material opportunity cost added to the industrial biofuel production cost. It is given by the dual variable associated with biofuel demand constraints that are equal to the variation in the farming and industrial joint profit due to the production of an extra ton of biofuel (Treguer et al., 2005).

The main hypotheses of the model OSCAR are the following: (1) farmers are considered to be 'price takers'; (2) the agro-industrial sector is closed to imports; (3) co-product crop demands are considered totally elastic; (4) biofuel demand by refiners is totally elastic and their valorisation is fixed to corresponding fossil fuel prices. In addition, as the farming model is based on historic data (RICA), the only farms enable to produce a crop are the ones which have already grown this crop at present time or in the past. It can be viewed as a know-how patrimony or a climatic and pedologic potential. Nevertheless, farmers could choose to cultivate new crops if the economic signal is incentive. Then, marginal cost of biofuel production would probably decrease (especially for rapeseed production).

The aim of the coupling procedure between the OSCAR and the refinery model is to release the hypotheses 4 above. Comparison between marginal biofuel production costs and biofuel

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[9] data based on Rozakis et al. (2005)

valorisation at associated engine fuel price has already been made by the Public economics department of INRA to determine tax exemption need considering uncertainty (see Rozakis and Sourie, 2005) or not (see Rozakis and Sourie , 2001). However, these previous works suppose the existence of a linear relation between crude oil prices and engine fuel market prices. In fact, the complexity of refining shows that such relations are not obvious. In addition, biofuel production are supposed to be sold at their associated engine fuel market price. In fact, the refiner willingness to pay for biofuels can be different from engine fuel prices. Consequently by releasing the hypothesis 4 thanks to the use of the refining model we are able to take into account the refining complexity and improve our understanding of biofuel markets.

3.2. The French refining model

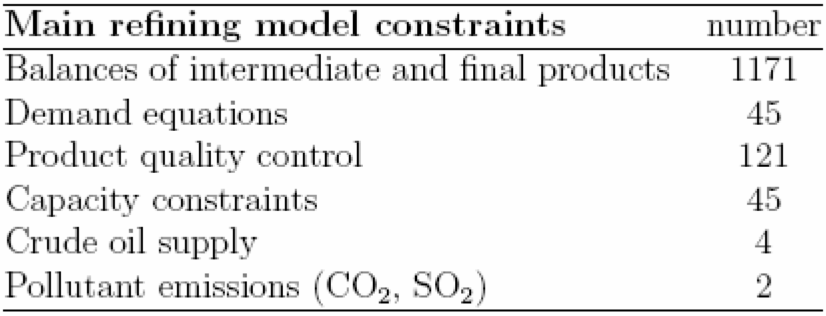
3.2.1. General description

The French refining model is a mono-refinery optimization model based on linear programming[10]. This model can be used for short-run and long-run determination of the refining flow chart. In the first case, annual refining costs are composed of operating variable costs of the various refining units (chemicals, utilities...). For long-run analysis, capital expenses (investments) and fixed costs (maintenance, labour...) are added to the previous costs. The objective function allows former cost minimization under several constraints: end-product demands and specifications, refining capacities, crude oil supply and pollutant emissions (CO_2, SO_2). The refining model determines end-product blend compositions, utility consumptions, investments, imports and exports but also marginal production costs, marginal costs related to specification constraints, CO_2 and SO_2 total emissions from the refinery. An exhaustive description of the refining model is provided in Saint-Antonin (1998).

3.2.2. Variables, parameters and equations

Physical flows between refining units from crude oil to end-use oil products along with pollutant emissions (CO_2, SO_2), utility uses, investments, imports and exports are the main variables of the refining model in our long-run analysis. In the French refining model, crude oil provisioning is schematized by four representative crude oils (Brent, Arabian Light, Arabian Heavy and Forcados) (Khebri, 1993; Saint-Antonin, 1998). Crude oils are then processed by refining units (distillation, cracking, visbreaking, hydro-treatment units...) in order to produce various refined products (propane, butane, naphtha, gasoline, jet fuel, diesel, domestic fuel, heavy fuel, bitumen...). In the model supply ratios, capacity of the units, end-product demands, market prices, technical specifications and the data matrix of technical coefficients (intermediary products and utility yields for each unit) were fixed as parameters. Main constraints are presented on table 2.

Table 2: Refining model composition



Main refining model constraints	number
Balances of intermediate and final products	1171
Demand equations	45
Product quality control	121
Capacity constraints	45
Crude oil supply	4
Pollutant emissions (CO_2, SO_2)	2

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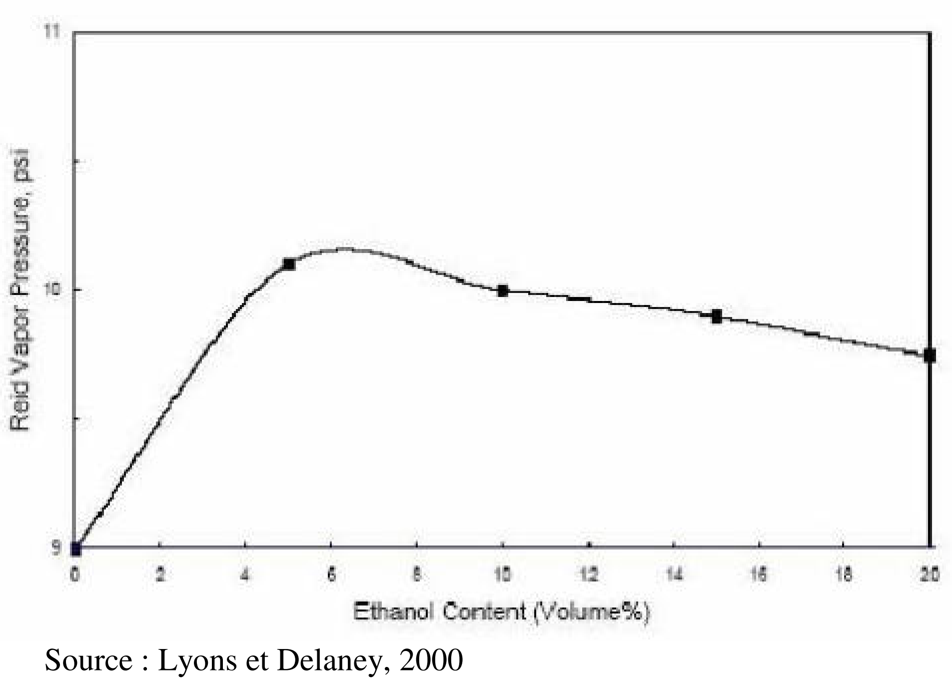
[10] developed by the IFP from original OURSE^{TM} (Economics Studies Division, IFP).

The main hypotheses inherent to the refining model are: (1) refiners are considered as 'price takers'; (2) biofuel buying prices, generally obtained from the market price do not reveal real biofuel opportunity cost of production. Hypotheses (2) is released thanks to the following coupling procedure.

3.2.3. Biofuel concern

In order to handle the biofuel question, the use of biofuel by refiners is considered to be only constrained by the respect of fuel specifications. We do not fix a maximal biofuel blending rate as it is imposed by regulations (5% blend in volumen). Indeed it is obvious that this regulation is not consistent with the blending target objectives. It is, for example, impossible to comply both with the minimum 5.75% blending target in energy in 2008 and the 5% maximum blending target in volume for ethanol and VOME, and the E.C. is presently revisiong this regulation. Nevertheless, the maximum blending regulation can be justified by the evolution of ethanol/gasoline mix volatility when the share of ethanol increases. Some adjustments of the refining model were necessary to enable the refiner to take this phenomenon into account.

For this purpose, integer variables were used to perform the modeling of non-linear volatility properties of ethanol mixed with gasoline. Indeed, gasoline/ethanol blend volatility depends on ethanol proportion. This property is often a barrier for ethanol incorporation in gasoline because of gasoline specifications. Nevertheless, as shown on figure 1, after a 6% blend in volume Reid vapor pressure of ethanol/gasoline blend decreases. Consequently, the non-linear rule of ethanol and gasoline mix volatility might allow refiners to incorporate more ethanol in gasoline.



Source : Lyons et Delaney, 2000

Figure 1: RVP Impacts of Adding Ethanol to Gasoline

However the refiner can also use ethanol to produce ETBE and blend it with gasoline up to 15% in volume. Concerning VOME, nothing seems to constraint incorporation in diesel up to 8% in volume, all the more that it can be used up to 30% in captive fleet.

Furthermore, as the general tax on pollutant activities is very dissuasive for refiners, it is assumed that they will incorporate the total amount of biofuel this tax induces, and no more because by doing so they would not benefit from the tax exemption elsewhere. The dual variable associated with the biofuel demand constraint provides an important information for determining the tax exemption need. Indeed, these dual variables could be interpreted as the long run marginal production costs of the refiners. In other words, these dual variables represent the refiner willingness to pay, i.e. the maximum price, for having one more ton of biofuel.

3.3. The coupling procedure

The coupling procedure implemented in this work[11] finds its origin in the obvious complementarity between the agro-industrial model and the refining model to give a realistic representation of the whole range of biofuel production chains and final use. For each year considered in the following prospective analysis, we run an external coupling procedure with coordinated simulations between the two models. The minimum tax exemption needed to place on the market the targeted quantity of biofuel can thus be determined. It also provides the LCA with some data resulting of the agent economic choices. Three optimizations are required. The one for the agro-industrial model obliges farmers and industrialists to produce the targeted quantity of biofuels. Two successive optimizations 'with' and 'without' biofuel use are then undertaken with the refining model. In both cases, the long-run analysis of the refining activity will reveal how the refiner meets the same end-product demands minimizing its costs. The situation 'without' biofuel means that the refiner is not allowed to incorporate biofuel in order to answer his oil end-product demands. He can use methanol to produce MTBE, an other oxygenate component produced from fossil sources which improves the quality of gasoline in a similar way than ETBE. In the situation 'with' biofuels, he can use ethanol in direct blending with gasoline or produce ETBE. Nevertheless, in this case refiners can no more produce MTBE since French refiners usually convert their MTBE units in ETBE units to incorporate ethanol. The refiner can also incorporate EMHV in direct blending with diesel.

The procedure is as follows for each year and each crude oil price considered:

1. Optimizing the OSCAR model 'with' biofuels to obtain the agro-industrial marginal cost to produce the targeted quantities of biofuel. The cultivated area of biofuel crops are also noticed for the LCA;

2. Optimizing the refining model 'without' biofuel in order to record crude oil demand and CO_2 refining emissions when end-product (fuels) demands are met by fossil sources;

3. Optimizing the refining model 'with' biofuels in order to obtain the refiner's willingness to pay for the ultimate ton of biofuel it has to incorporate. Furthermore, the model determines also the crude oil demand and the CO_2 emissions from the refining activities when using biofuels.

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[11] The present coupling procedure was developed in an ADEME project joining INRA, IFP research teams. For further details see Rozakis et al., 2005

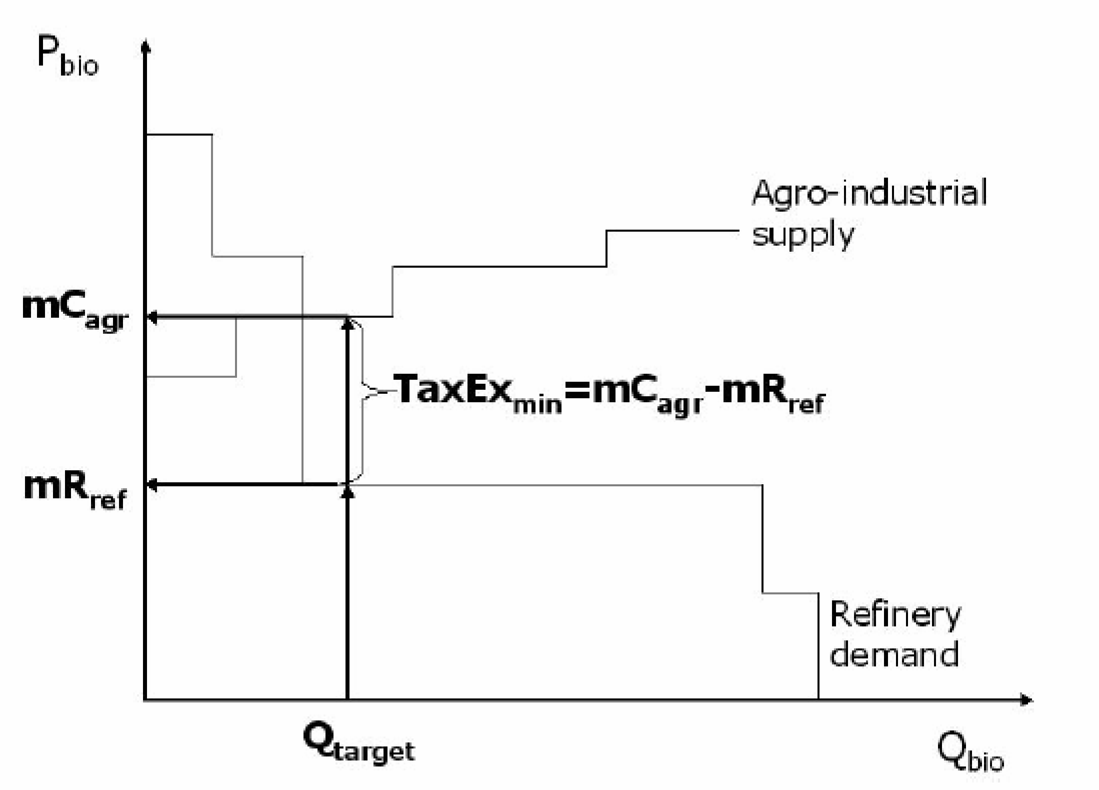


Figure 2: Tax exemption determination by coupling procedure

Post optimization calculations using both model outputs are then necessary to determine the minimum tax exemption amounts ($TaxEx_{min}$) the planner has to set up in order to reach biofuel targeted quantities (Q_{target}) for each production chain (see figure 2). This value is obtained by the difference between the cost of the last ton of biofuels the industries have to produce (optimization 1) and the refiners' willingness to pay for the ultimate ton of biofuels he has to demand (optimization 3). In short, the government should have to compensate the gap between the agro-industrial marginal cost of biofuel production (mC_{agr}) and the marginal revenue of biofuel for refiners (mR_{ref}). We determine a 'minimum' tax exemption because, by seeking a long-run equilibrium, we assume that refiners are completely free to invest in the refining units they need. The refining model is a deterministic model and consequently refining investment decision does not take into account uncertainty. In fact refiners cannot invest as freely as it is supposed in this paper.

4. ACCOUNTING FOR GHG EMISSIONS REDUCTION

4.1. LCA methodology

LCA enables to evaluate the environmental impacts caused by an asset production, use and end of life or a process. Thanks to this method, it has now been proved that biofuels used in substitution to conventional fossil fuels reduce GHG emissions (see ADEME et al., 2002; EUCAR et al., 2006). Nevertheless, assessments are still controversy due to the diversity in their results. The main interest of the LCA provided in this study is the use of the farming and refining LP models which differ from current LCA. Thus, we bring more precise information on the farming and the refining steps in the estimation of the potential GHG emission benefit thanks to biofuels use in the French transport sector. This approach makes it possible to give more accurate information on the technico-economic choices of farmers and refiners and to avoid the question of emissions allocation between gasoline, diesel and all co-products of the refinery (for allocation purpose see e.g., Babusiaux, 2003, Pierru, 2006, Tehrani, 2006).

In order to realize the biofuel LCA, two scenarios are compared. A «Business as usual» scenario, where GHG emissions are evaluated for the whole fuel production and utilization chain, and it is supposed that no biofuels are consumed. And a «Biofuel use» scenario where the influence of biofuel incorporation on GHG emissions is assessed.
On this basis, we follow the 4 main steps of the LCA method:

1. Goal and scope definition, where the objectives of the study for an attempted utility are described;

2. Inventory, where a flow diagram is used to describe physical flows like emissions and the use of raw material in order to obtain the attempted utility;

3. Impact assessment, where the previous flows are gathered into impacts;

4. Interpretation, where the various scenarios are compared.

In order to compare the two main pathways, conventional fuels and biofuels, several steps from material extraction to final use of fuel are distinguished (see figure 3). For each step, energy consumption and GHG emissions are estimated. The difference between the whole GHG emissions of each scenario gives the potential GHG emission reduction due to biofuels in France. This calculation is made for the three time frames we are studying (2008, 2010 and 2020) and for a 70$/bbl crude oil price.

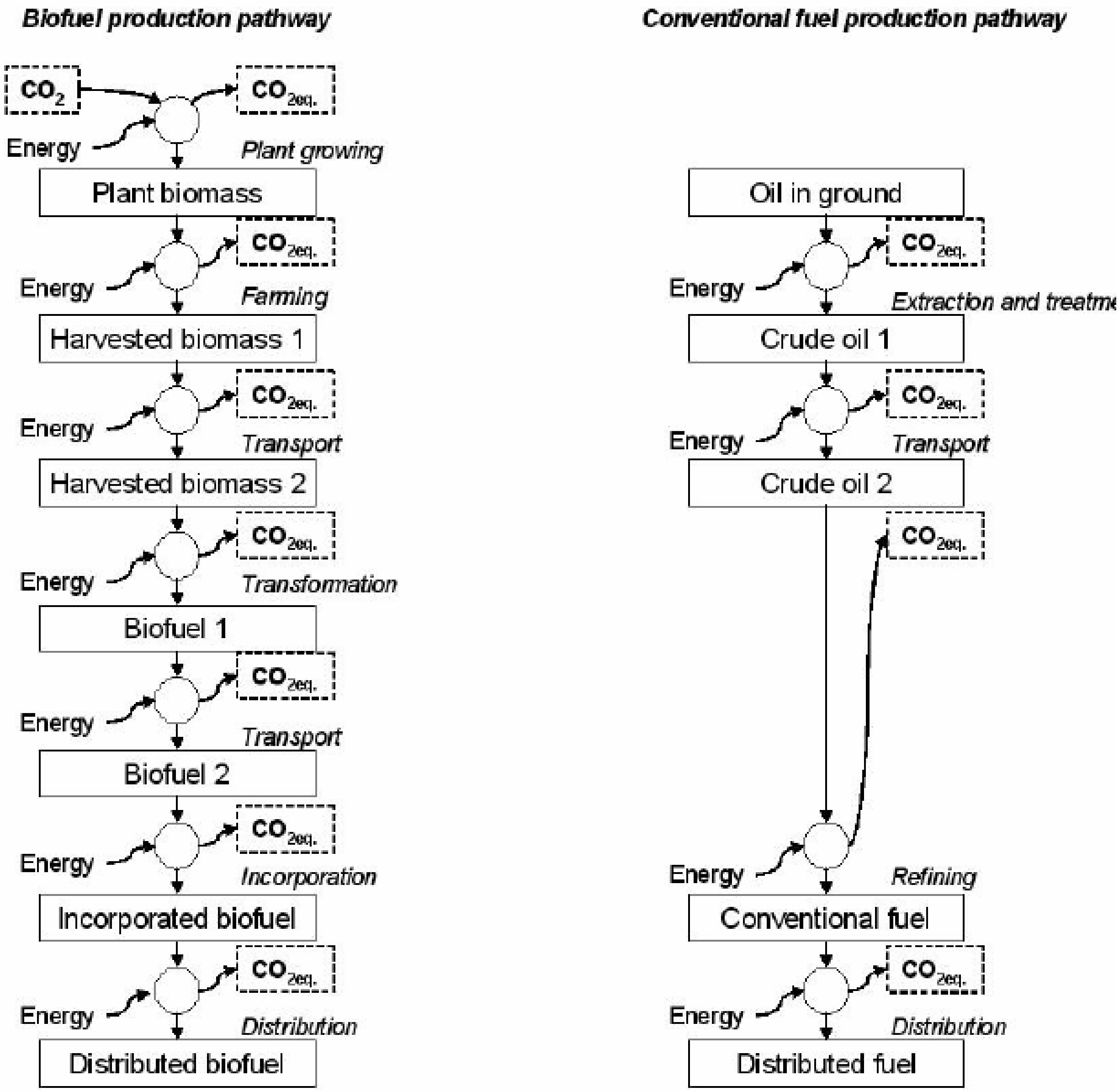


Figure 3: LCA sheme

4.2. Data used

4.2.1. General assumptions

The GHG balance is based on CO_2, CH_4 and N_2O flows from crude oil extraction or biomass cultivation to fuel use in the vehicle. A global warming potentials (GWP) are assigned to each gas (see table 3). In the agricultural sector, the GHG emissions from energy consumption as well as emissions of N_2O are taken into account. However, the impact of infrastructures and services are supposed to have a minor impact on the final result.

Table 3: Global warming potentials of the GHG assessed in this study (g eCO_2/g)

	CO_2	CH4	N_2O
GWP	1	23	296

Source: IPCC (2001)

The two scenarios we compare refer to the French situation, regarding in particular electricity mix and energy supply. Nevertheless, technologies are supposed to remain the same between the three scenarios studied (2008, 2010 and 2012).

4.2.2. Conventional pathways

The GHG balance of conventional gasoline and diesel pathways relies on the results of the refinery model, namely the total amount of final fuel produced (and consumed), the quantity of crude oil used, by region of import, as well as the total amount of CO_2 emitted by the refinery for fuel production. Crude oil need, which is given by the refining model, enables the evaluation of crude oil production GHG emissions. By summing the previous GHG emissions we obtain the well-to-tank GHG emissions.

Extraction and treatment of crude oil are considered as one single step. 96% of external energy consumptions are supposed to come from natural gas (62%), electricity (19%) and diesel oil (15%). The remaining 4% come from residual oil (2%) and gasoline (2%) (GMC et al., 2001). Energy consumptions considered in this study are limited to associated gas (a part is supposed to be used for electricity generation, with a yield of 31%) and diesel oil. Total energy consumption for crude oil extraction account for 2.3% of the energy content of produced oil. Losses during crude oil extraction have also been taken into account at a rate of 0.37% (GMC et al., 2001). It is supposed that there is no methane leakage, associated gas is either flared or used for energy consumption on site. Gas flaring is estimated for each region and vary from 2.6 m^3/t of crude oil in the North See to 9.5 m^3/t in Sub-Saharan Africa. GHG emissions of crude oil transport relies on energy consumption during transport. Crude oil is transported either by pipelines or by tankers. Three transport steps have been considered:

- from oil field to the export place, by pipelines;
- from export place to the import place, by tanker or pipelines;
- from import place to refineries, by pipelines.

Pipelines length for transport from oil field to the export place have been estimated from (CPDP, 2004). The total distance is then calculated as the average distance, weighted by total oil import by region. It is supposed that energy for crude oil transport comes from fuel-oil. Onshore pipelines are supposed to consume $2.4.10^{-3}$ MJ/(t.km) and offshore pipelines 0.48 MJ/(t.km).

We also use average distances between import and export places, that have been estimated from CPDP (2004). The total distance is then calculated as the average distance, weighted by total oil import by region. Traffic breakdown is based on Hawdon (1991). Two types of tankers have been used : 100, 000 tons and 300, 000 tons. Their energy consumption have been evaluated by The Green Tankers, Franceship Armement and Total Maritime Direction. Energy is supposed to come from fuel oil. Finally, the average distance between import place and refineries have been calculated with distances covered by pipelines networks and annual transport capacity. Energy is used as electricity and the consumption is supposed to be $2.4.10^{-3}$ MJ/(t.km) [Source: Société du Pipeline Sud Européen].

Leakage or evaporation of hydrocarbon during transportation are also included in the calculation. There are few data on losses of hydrocarbons. Data used in this study are reported on table 4.

Table 4: Oil spills during transportation (ppm)

	Losses		
	Min	Average	Max
Transport by tanker	4.2	19	45.9
Transport by pipeline	0.1	0.51	1

Source: IFP, Oil spills intelligence report, Concawe and ITOPF

The GHG emissions of the refining activity are provided by the refinery model. They are mainly due to the use of energy by refining units. Refining units are supplied with various utilities such as fuel, electricity, high pressure vapour or low pressure vapour or even natural gas. The flow chart obtained by optimization makes it possible to determine the use of each unit use and their needs for each utility. Thus, GHG emissions from the refinery are given by the model.
Then fuels are transported either by pipelines, trucks, trains or barges. France uses mainly pipelines. Distribution network of liquid fuels from refineries to delivery stations was modeled in CPDP (2004). Fuel transportation by barge is supposed to consume 0.25 MJ/(t.km) as fuel-oil, by rail 250 L/100 km as diesel oil or 16.1 kWh/km as electricity. Trucks are supposed to consume 32.8 L/100 km as diesel oil. No fuel leakage has been taken into account for fuel distribution. This step is common to conventional diesel and gasoline, and biofuels.

4.2.3. Biofuel pathways

Three biofuel pathways are evaluated: (1) ethanol or ETBE from sugar beet; (2) ethanol or ETBE from wheat; (3) VOME from rapeseed. Concerning the biomass cultivation step, carbon stored in agricultural soils (see table 5) and GHG emitted by farming are taken into account. Farming GHG are mainly due to energy consumption (trucks...) and fertilizers and phytosanitary use (especially for N2O emissions)(ADEME et al., 2002). The harvested biomass is then supposed to be transported by truck. Biofuel emissions are allocated using the «substitution» method, i.e. all the emissions of the conversion process are allocated to the biofuel and a credit for the use of co-product in breed feeding or glycerine production is then deducted (EUCAR et al., 2006).

Table 5: Coefficients of carbon sequestration in the soil by different crops

Crop	Yield	C sequestration flow
Unit	*t/ha*	*tC/ha/yr*
Wheat	8.5	0.48
Sugar beet	14 (sugar)	0.32
Rapeseed	5.0	0.32
Fallow land	-	0.08*

* estimated by the INRA
Source : Boiffin et al. (1986); Wylleman (1999)

Regarding biofuel transportation to the refinery, two different schemes are used: ethanol is supposed to be transported by train to the refinery, on an average distance of 350 km and VOME is supposed to be transported to the refinery by truck for 7% (on an average distance of 400 km), by train for 28% (400 km) and by barge for 65% (60 km) (ADEME et al., 2002). The incorporation step in the refinery is supposed to have an impact only for ETBE which is produced from ethanol and isobutylene in the refinery (see table 6).

Table 6: Energy consumptions for ETBE synthesis (7.4 t ETBE/h)

	ETBE synthesis
Electricity (kWh)	53.2
Steam (t/h)	5.1
Isobutylene (t/h)	3.92
Ethanol (t/h)	3.48

The chemical reaction of ETBE production is as follow:

0.47 t Ethanol + 0,53 t Isobutylene . 1 t ETBE

4.2.4. Vehicles energy consumption and GHG emissions

Final emissions of vehicles with fuel use are estimated with average data, considering that only conventional fossil fuels are causing GHG emissions and that biofuels are «CO_2 neutral». The average GHG emission is taken as 140 g eCO_2eq/km (for a consumption of 190 MJ/100 km) for gasoline and as 128 g eCO_2eq/km (for a consumption of 172 MJ/100 km) for diesel oil.

5. FRENCH BIOFUEL PLAN EVALUATION IN 2008, 2010 AND 2012

5.1. Prospective scenarios description

In order to study the French biofuel plan, three scenarios were built. One for 2008, one for 2010 and one for 2012. They dealt mainly with technological improvements, prices, policies and demands in relation with biofuel production chains.

5.1.1. The French biofuel plan

The French biofuel plan imposes the following rates in fossil fuels blending objectives by means of the general tax on pollutant activities (see table 7).

Table 7: Biofuel incorporations targeted by the French government in 2005

	Objectives	Gasoline demand	Ethanol eq.	Diesel demand	VOME eq.
Units	*% NCV*	*Mtons*			
2008	5.75%	9.996	0.915	34.563	2.286
2010	7.0%	9.123	1.017	36.088	2.905
2012	8.0%	8.315	1.059	37.437	3.445

In this work we assume that ethanol production is equally divided between wheat and sugarbeet. Considered using gasoline and diesel demands, the biofuel blending rates provide the biofuel quantity the French government wants to place on the market. It is for these biofuel quantities, the quantities farmers and industrialists have to produce and refiners have to incorporate, that we will calculate the minimum tax exemption the government has to set up as well as gain in GHG emissions.

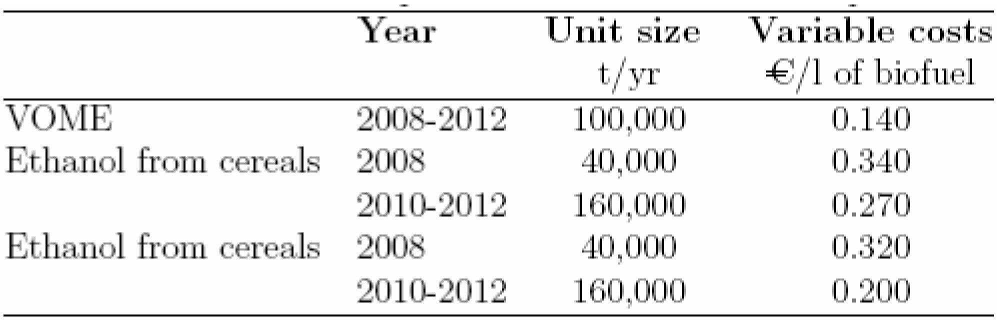
5.1.2. Price considerations

Dealing with prices, we decided to study three different crude oil price scenarios for each year using correlations rather than forecasting price evolutions.
Three Brent crude oil price were studied: 50$/bbl, 70$/bbl and 90$/bbl. The price of 70$/bbl is our middle price scenario because on august 12th 2005, Brent reached the price of 67$/bbl and this price has been increasing since 2003. We can note that since April 2006, the Brent crude oil price has passed the price of 70$/bbl. In the refining model, correlations, based on IFP sources, were necessary to evaluate the impact of different crude oil price scenarios on petroleum product prices. In addition, the agro-industrial model does not take into account changes in farmers production costs when the crude oil price varies. Concerning co-products, some hypotheses on their prices have been drawn up. The prices which have been retained correspond to the 2005 market situation and we assume these values to remain constant until 2012. Glycerine is priced at 125$/T, cattle cakes at 150$/t and DDGS at 112$/t.

5.1.3. Industrial units evolutions in technology

In this work, we assume that the technology can be improved. Nevertheless, new technologies cannot emerge. Thus, biofuel technology can become more efficient thanks to scale effects and the refiner is capable of improving its technology by investing, especially, in hydro-technologies. Processing yields in biofuels and co-products depend on the year we are considering in order to represent technology improvement. It is considered that VOME technology will be mature as early as 2008, whereas ethanol technology is expected to become more efficient between 2008 and 2010. Different processing costs based on unit sizes were implemented as shown in the following table 8 (see Mavrotas and Rozakis, 2005).

Table 8: Industrial production cost evolutions expected in 2005



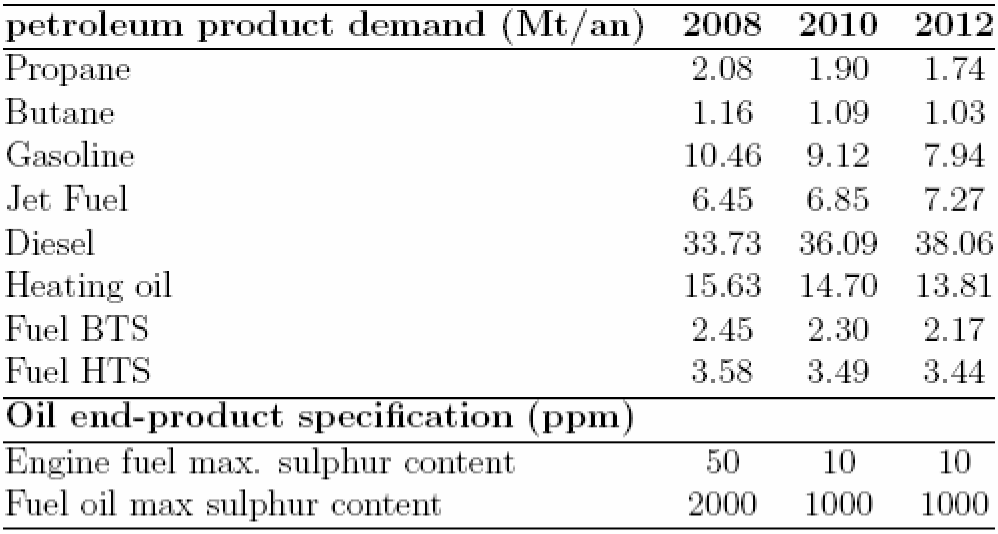
	Year	Unit size t/yr	Variable costs €/l of biofuel
VOME	2008-2012	100,000	0.140
Ethanol from cereals	2008	40,000	0.340
	2010-2012	160,000	0.270
Ethanol from cereals	2008	40,000	0.320
	2010-2012	160,000	0.200

Source : IFP

5.1.4. Fuel specifications and demand evolutions

In order to evaluate the French petroleum end-product demands a predictive model based on trends and linear programming is used. Engine fuels demand, gasoline and diesel, were in particular estimated according to parameters based on the fleet and the freight traffic (Rozakis et al., 2005). On this basis, the engine fuels demand is supposed to emphasize the imbalance in favour of diesel. Apart from diesel, the other end-product demands are expected to decrease (see table 9). Furthermore, fuel specifications will become more stringent concerning sulphur content and other particles.

Table 9: petroleum parameter evolutions expected in 2005



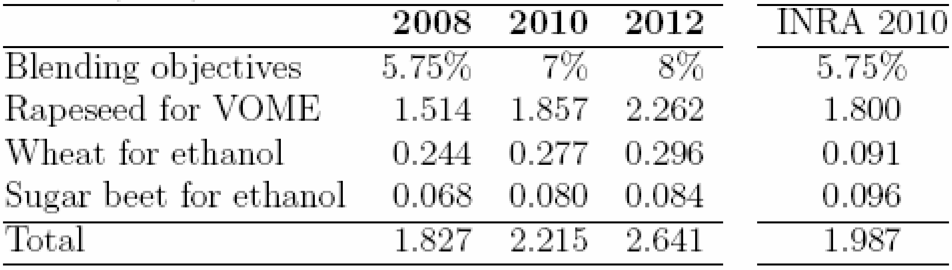
petroleum product demand (Mt/an)	2008	2010	2012
Propane	2.08	1.90	1.74
Butane	1.16	1.09	1.03
Gasoline	10.46	9.12	7.94
Jet Fuel	6.45	6.85	7.27
Diesel	33.73	36.09	38.06
Heating oil	15.63	14.70	13.81
Fuel BTS	2.45	2.30	2.17
Fuel HTS	3.58	3.49	3.44
Oil end-product specification (ppm)			
Engine fuel max. sulphur content	50	10	10
Fuel oil max sulphur content	2000	1000	1000

Source : IFP

5.2. Results and discussion

Main results deal with biofuel crops land use, biofuel competitiveness and tax exemption need to favour biofuel development as well as GHG emission reduction assessment thanks to biofuel use. Biofuel crops land use If we consider the need of land for biofuel crop productions, we can observe that as early as 2008 the entire French set-aside land of about 1.5 Mha will be slightly insufficient to insure the biofuel production targeted by the government (see table 10).

Table 10: Land need for biofuel crops production from the agro-industrial model (Mha)



	2008	2010	2012	INRA 2010
Blending objectives	5.75%	7%	8%	5.75%
Rapeseed for VOME	1.514	1.857	2.262	1.800
Wheat for ethanol	0.244	0.277	0.296	0.091
Sugar beet for ethanol	0.068	0.080	0.084	0.096
Total	1.827	2.215	2.641	1.987

As soon as biofuel production exceeds the extent fallow lands, competition for energy and food land use arises (Treguer et al., 2005; Ignaciuk et al., 2006). VOME and ethanol crops show different evolutions. The more rapeseed is to be produced, the more food crops have to be abandoned by farmers. As food crops are generally more profitable than biofuel crops, the marginal rapeseed cost of production increases (see table 11 and figure 4).

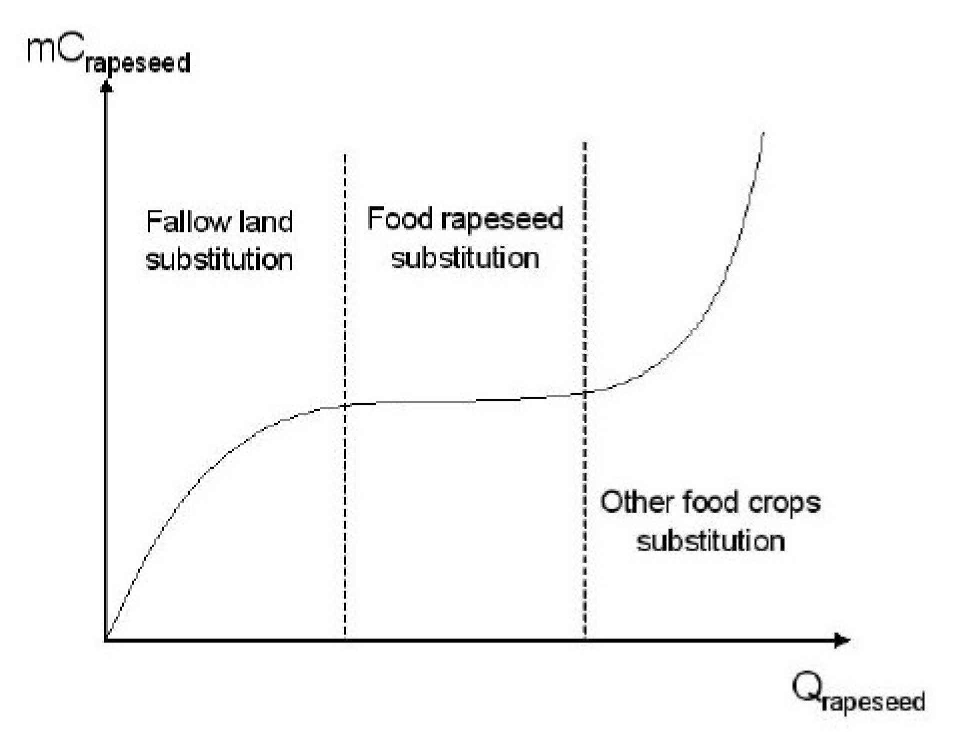


Figure 4: Biofuel rapeseed supply curve

For each year we have great change in rapeseed marginal cost because of the high demand on rapeseed which imposes farmers to first exceed the set-land land, then substitute a first food crop, then a second, and so on.

Marginal production costs of ethanol crops are more stable. They remain the same for wheat (mC=0,37€/l) and nearly the same for sugar beets. The slight decrease for in sugar beet marginal cost is due to CAP reform[12]. For wheat and sugar beet, the demand for biofuel is less important and the same crop is substituted from 2008 to 2012. For this reason the marginal cost remains the same.

5.2.1. Tax exemption results

Table 11 shows the results of the coupling procedure. When minimum tax exemption is negative, then there is no need for tax exemption because biofuels are competitive and both refiners and farmers would use more than the targeted quantity.

What appears first is that biofuel competitiveness depends on crude oil price and fuel demand (years). As we can see, through the years the marginal quantity of VOME become less and less attractive whereas from 2008 and 2010 the competitiveness of ethanol is much better.

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[12] Mainly a «39 percent price cut over two years beginning in 2006/07 to ensure sustainable market balance» (E.C., 2005). In fact the change in sugar beet marginal cost should occur just before 2008 whereas in our modeling it occurs just after 2008.

Table 11: Biofuel tax exemption results in €/hL

	Oil price	Marginal costs		Marginal revenues		Min. tax exemption	
	($/bbl)	Ethanol	VOME	Ethanol	VOME	Ethanol	VOME
2008	50	47	39	23.8	29.2	23.2	9.8
	70			33.2	39.2	13.8	-0.2
	90			44.0	48.9	3.0	-9.9
2010	50	42	48	27.6	28.2	14.4	19.8
	70			37.8	38.6	4.2	9.4
	90			48.0	48.4	-6.0	-0.4
2012	50	42	76	26.7	28.8	15.3	47.2
	70			37.7	38.9	4.3	37.1
	90			47.8	48.5	-5.8	27.5

Two reasons explain such results. On the one hand, the agro-industrial marginal costs of VOME production will increasing because of the high demand of rapeseed dedicated to biofuel production whereas the sugar beet marginal cost[13] will decrease in 2010 because of the Common Agricultural Policy reform. On the other hand, refiners seems to be more interested in VOME than in ethanol because of the imbalance in fuel engine demand. The biofuel marginal revenue will increase with the crude oil price as well as with the increase in demand. As a consequence of these two evolutions, VOME appears much more competitive than ethanol in 2008 whereas the VOME marginal quantity becomes less competitive in 2010 and 2012. We can note that ethanol is not competitive with gasoline production in 2008 for any crude oil prices below 90$/bbl whereas in 2010 and 2012 ethanol begins to be competitive for a crude oil price above 70$/bbl. VOME will be very competitive with fossil diesel production in 2008 for a price near to 70$/bbl what is at present the case. In 2010, VOME becomes competitive for a crude oil price of about 90$/bbl whereas in 2012 it is not profitable to impose the volume required. Nowadays, as the French government wants to give a strong incentive to the various agents of biofuel production chains in order to promote a sustainable development of biofuels, the tax exemptions were set up at 25€/hl for VOME and 33€/hl for ethanol. Nevertheless, the question of the optimal management of tax exemption amount is rising for policy efficiency purposes. And as it is shown in table 11, the determination of the optimal tax exemption amount would have to take into account the crude oil price as well as the year we consider (petroleum product demand and specifications). Thus, in the future the ethanol tax exemption might be reduce whereas VOME one might increase.

5.2.2. LCA results

The results of LCA show that the use of biofuels could help save, over the complete chain from crude oil extraction or biomass cultivation to fuel use, between 7 and 11 Mt CO_2 equivalent (eCO_2) by year, depending on the year considered. Thus, biofuels would make an average reduction of 5% in GHG emission possible compared with the «Business as usual» situation (see table 12).

In table 13, a comparison of GHG emissions savings thanks to biofuel use is provided by step. Positive figures correspond to GHG emission reduction and negative ones to GHG emission increase.

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[13] As the ethanol marginal cost from sugar beet is higher than the one from wheat (0.37 €/hl), we retain ethanol from sugar beet marginal cost to determine the minimum tax exemption need.

Table 12: Overall GHG emissions reduction obtained by the use of biofuels

	2008	2010	2012
Biofuel rate (%)	5.75%	7%	8%
GHG emission reduction (Mt eCO_2/yr)	7.2	9.7	10.9
GHG emission reduction (%)	4%	5%	6%

The major part of emission reductions occurs at the fuel use in the car. In fact this GHG emission saving is due to the CO_2 recycling by plants, i.e. the CO_2 emitted by biofuel combustion is partially sequestrated by plants during photosynthesis. Despite the fact that carbon storage in soil is taken into account, the (crude oil and farming) production step implies more emissions ‘with’ biofuels than ‘without’, because of the cultivation step. Processing contribution in GHG emissions, accounting for biofuel and refining processes, can be either positive or negative. On the one hand, GHG emissions should increase because of the biofuel production by industries but, on the other hand, refineries are expected to reduce their GHG emissions thanks to the use of biofuel reduces their fossil fuel demand. In fact this second assumption is not necessary true because the refining investments (each unit having a specific need in energy from various sources) and the flow chart ‘without’ and ‘with’ biofuel is different. Consequently, the use of biofuels by refiners do not necessary decrease GHG emissions in the refining process. Further research should be undertaken to determine biofuel influence on refining investments and, thus, GHG emissions. Nevertheless, considering the whole pathways, biofuels always allow GHG emission savings. Furthermore, the distribution step contribution to GHG reduction is null because the same quantity (in tons) of fuel will be distributed in the two scenarios.

Table 13: GHG emissions reduction between the two scenarios by step (Mt eCO_2/yr)

	2008	2010	2012
Production	-1.1	-0.7	-1.5
Transportation (all steps)	0.1	0.3	0.2
Processing	-0.6	0.2	-0.2
Distribution	0	0	0
Fuel use in cars	8.8	10	12.4
Total	7.2	9.7	10.9

The calculation of possible GHG emissions reduction on the entire life cycle by the introduction of biofuels shows that the objectives set by the French Government in 2004 (Plan Climat 2004) are realistic. These objectives are indeed to reduce by 7 Mt eCO_2 the emissions in the road transport sector by 2010 by the use of biofuels.

6. CONCLUSION

An economic and environmental analysis of the French biofuel plan in 2008, 2010, 2012 is made using the coupling procedure between agro-industrial and refining LP models developed by Rozakis et al. (2005). This plan is efficient concerning GHG emission reduction nevertheless it could nevertheless probably be better tune in the public economics sphere. Biofuel can become competitive with fossil fuels production for the refiner depending on the crude oil price and petroleum product demand. Today, VOME is already more or less competitive but the high demand in rapeseed may decrease the economic appeal of the marginal quantity of VOME required by the French government. Ethanol production does not seem very competitive because of the imbalance in engine fuel demands. Nevertheless, new biofuel technologies and high crude oil price can makes biofuels become more competitive.

In addition, biofuel use makes it possible to save about 5% of GHG emissions in the road transport sector in comparison with the «Business as usual» situation. The gain is especially due to the CO_2 recycling by plant.

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