Questions of costs about the French bio-fuel sector by year 2010

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Abstract

By the end of year 2010, each member state of the European Union (the EU) ought to incorporate 5.75% of bio-fuels in the total of fuels used for transportation purposes. In order to achieve such a target, tax incentives are implemented by the French government given that the production of bio-fuels still remains unprofitable, even if oil prices are about $60/barel. After a brief introduction (1), we will first demonstrate the importance borne by the cost of agricultural raw material in the total cost of bio-fuels (2). For this purpose a sequential multi annual LP model is used (3). Emphasis must be placed on the possible competition between food and energy crops, should the production of energy crops require land exceeding the mandatory 10% set-aside (4). An assessment of the profitability of the different types of bio-fuels is then carried out (5).

Keywords : Bio-fuels, Common Agricultural Policy, Opportunity cost, Energy Crops, Kyoto Protocol.

JEL classification: C61, Q18, Q42

1 Introduction

Ensuring a safe and environmental-friendly supply of energy has been a strong incentive to focus on the development of alternative fuels since the oil shock in 1973. As environmental global issues become of prime importance, as the EU attempts to comply with its international commitments, replacing transport fuels by alternative fuels is recommended to member states in the immediate future. As a matter of fact, the transport sector accounts for more than 30% of final energy consumption in the EU and is expanding along with carbon dioxide emissions. From an ecological point of view the EU Commission White Paper « European transport policy for 2010: time to decide » calls for reducing the dependence on oil (98%) in the transport sector by using alternative fuels such as bio-fuels. Moreover the EU Commission Green Paper « Towards a European Strategy for the Security of Energy Supply » sets the objective of 20% substitution of conventional fuels by alternative fuels in the road transport sector by year 2020. In the directive adopted by the European Parliament in 2003 following the Council position on the promotion of the use of bio-fuels or other renewable fuels for transport (Council of the EU, 25/2/2003), member states are prompted to ensure that a minimum proportion of biomass and alternative fuels are placed on their markets setting appropriate national indicative targets. Such goals are designed to attain a level of 2% of all liquid fuels for transport purposes until the end of 2005 and 5.75% by 2010. It seems that France is in a comfortable position to

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achieve these targets, being the first of all European countries to have launched an ambitious bio-fuel program.

Two types of bio-fuels are produced in France: RME[1] and Ethanol/ETBE[2]. RME is added to gas-oil and ethanol/ETBE is mixed with gasoline. Each production chain mirrors the two sides of the fuel market in France.

- RME is produced from rape-seed and generates two co-products in the transformation process: cattle cakes and glycerine, both of which have an important market value.
- Ethanol is produced from sugar-beet or wheat and generates a by-product only in the latter case: DDGS[3].

Other agricultural raw materials are likely to be used more widely in the forthcoming years: sunflower (for Methyl Ester) and maize (for ethanol), but still at levels that are not comparable to the three main crops presented above.

Replacing gasoline in cars by bio-fuels could lead to a 7 million tons' decrease in carbon dioxide emissions, should their share reach the 5.75% level by 2010.

Behind this appealing perspective hides the embarrassing question of costs. The tax exemptions that are given away by the State to the bio-fuel chains are aimed at bridging the gap between costs and prices. Although the stakeholders of bio-fuels manufacturing entities have repeatedly announced a downward slopping curve for the costs as time goes by, they claim ever bigger tax exemptions from the State, which would tend to demonstrate that they face rising costs. This apparent paradox could be disentangled by focusing on the costs of bio-fuels.

We will now attempt to clarify the notion of cost in the context of the multi-product production system of arable agriculture. The sequential LP model that permits to estimate energy crop costs in the horizon of 2010 is detailed in section 3. Results regarding cross price interactions and supply curves for energy crops are provided in section 4, followed by the assessment of bio-fuel chains' costs and contribution to CO2 mitigation in section 5. The paper concludes in section 6 with additional remarks and discussion of the results.

2 How to deal with costs?

Assessing the costs of bio-fuels is difficult since producing bio-fuels couples a scattered agricultural production (more than 50,000 producers) with a highly concentrated industrial transformation phase (less than 10 plants). The question of the costs of bio-fuels must be addressed thoroughly. First, a distinction must be drawn between agricultural costs and industrial costs. Then, the concept of agricultural costs must be considered separately. Many concepts exist and might be equally chosen, albeit leading to different policy implications.

Our model is based on farm models chosen in the Farm Accountancy Data Network (FADN) that are merged to reflect the national supply of energy crops. A rigorous assessment of the costs is a necessary condition to deal with tax exemptions problems.

The challenges ahead of bio-fuels are to be found essentially in the agricultural phase of their production. Building a bio-fuel plant is not too difficult. Nevertheless, ensuring that this plant will be supplied with agricultural raw materials continuously over its lifetime needs to be more thoroughly discussed. The first Brazilian ethanol programme showed how the competition between food and energy markets (sugar versus ethanol, both produced from sugar cane) could jeopardize a large scale bio-fuel initiative.

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[1] Rape-seed Methyl Ester also called biodiesel

[2] Ethyl Tertio Butyl Ether, which is a compound made from ethanol (47%) and from isobutene (53%). Thus, Ethanol can either be added to gasoline directly, or after being mixed with isobutylene to form ETBE.

[3] Distillers Dried Grains with Solubles, used for cattle feeding.

The model we developed addresses the complexity of the production of energy crops in the midst of food crops in the farming systems. The competition between energy crops inside the set-aside land on the one hand, with food crops in the remainder of the land on the other hand, will determine the cost (and the availability) of energy crops for the transforming plants.

The question of costs for bio-fuels is a quite misleading one. It often proves hopeless to debate on this issue mainly because the concept of cost must be agreed upon in the first place. The cost of bio-fuels integrates the different stages of their production. The definition of such costs can be summarized is as follows:

Total cost of bio-fuels = (Agricultural costs of the raw material) + (Transformation costs) – (Incomes from the co-products)

2.1 The different agricultural costs

The definition of the costs of bio-fuels will depend on the type of cost chosen for the agricultural raw material. Basically, three possibilities may arise:

- The opportunity cost, which is the marginal cost of the least efficient producer so as to reach the demand.
- The mean cost, i.e. the weighted sum of the opportunity costs at the elementary farm level (the weight is given by the relative quantity of energy crop produced by farm *f*). The mean cost is necessarily lower than the opportunity cost and isn't suitable to measure the differential rents that appear between the producers.
- The "industrial cost", which equals the present price (or the expected future price) of the agricultural raw materials. This price is necessarily greater than the opportunity cost of the least efficient producer. Using this notion as the cost for the agricultural raw materials tend to deny the fact that bio-fuel are above all agriculture-based products, whose production takes places in a large variety of farms, which show a geographical, economic and technical diversity.

The type of cost chosen for this study is the opportunity cost (i.e. marginal cost). Beyond its advantages as far as microeconomic meaning is concerned, the opportunity cost also shows three main assets:

- As far as the agricultural stage of the bio-fuel production is concerned, the opportunity cost enables us to assess the minimal incentive price in order to introduce a given quantity of energy crops inside a given agronomic system.
- At the industrial stage of production, the opportunity cost of bio-fuels gives the minimal incentives (tax cuts) to be implemented by the State for the production of bio-fuels to be effective. The level of tax cut shall bridge the gap between the opportunity cost of bio-fuels and their market pricing.
- It enables studies on variations of surpluses to be led.

2.2 The complexity of assessing the agricultural costs of bio-fuels

The agricultural stage of bio-fuel production accounts for 22% (for ETBE made of sugar-beet) to 66% (for RME) of the total cost of bio-fuels. It seems therefore essential to assess as precisely as it may be these agricultural costs. However, estimating those costs is difficult for three main reasons (Sourie 2002).

First, the supply of raw material is highly scattered. More than 50,000 farms contribute to the national supply of raw material for bio-fuels, and this number may rise significantly further to the implementation of the European directive.

Secondly, the energy crops introduced in the cultural rotations of the farms are directly competing with the existing food crops. A good estimation of the raw material's costs can be led only if the energy crops are considered as crops among others in the rotations of the farms. This is the only way of understanding the substitutions effects between food crops and energy crops in these multi-output, multi-factors systems.

Finally, the raw material costs are tightly linked to the framework of the Common Agricultural Policy (CAP). As the bio-fuels production rises, the CAP is subject to major changes (The Luxembourg Compromise of course, but also the sugar market's reform). The establishment of a Single Farm Payment will not change the opportunity costs of energy crops, except for sugar-beet. However one should closely consider risks of idle land brought about by the reform of the CAP.

Therefore, it clearly appears that one could not summarize the agricultural costs of bio-fuels with a unique figure (as it may be done for the "industrial cost" notion of agricultural cost above) for all the 50,000 farms supplying the plants. This would be utterly simplistic if not completely false.

3 Methodology

The increased importance of the bio-fuel development program in France has stimulated our interest to improve modelling tools used in the past to evaluate public policy (Bard et al., 2000) and to attempt to build a bio fuel system encompassing model in order to complete recent studies that focus on a mono-chain bio-fuel analysis (concerning RME production, Costa and Réquillart, 2000). A micro-economic supply chain model has been developed for this purpose, based on the detailed description of the agricultural sector.

3.1 General outlook of the model

The production of bio-fuels is a two-staged process. First, the agricultural stage consists in supplying the energy crops. The industrial stage then transforms the raw material in bio-fuels that can finally be blended with fossil fuels.

Contrary to the industrial stage of production which is limited to a small number of plants, the agricultural phase involves a large number of farms, spread all across the French territory.

The OSCAR model integrates technical and economic constraints, in every single farm. The energy crops are part of a farming system where all the crops interact and compete with each other as far as agronomic, technical, administrative and economic constraints are concerned.

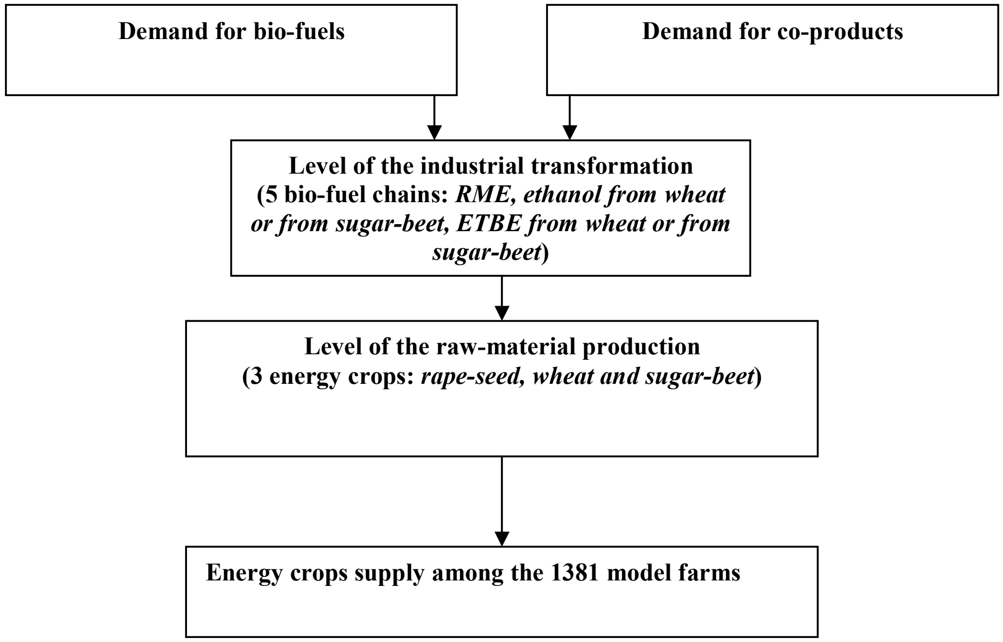
The model is a linear programming tool[4] (Williams, 1999) which simulates the supply of energy crops by a sample of model farms (following Hazell et al., 1987) chosen in the FADN[5], so as to meet an exogenous demand for bio-fuels. The energy crops are then processed in the industrial stage of production so as to end up as "bio-fuel".

A partial equilibrium approach has been chosen: prices for crops, demand, transformation costs and prices for bio-fuels are exogenous parameters.

[4] The software GAMS IDE has been used to carry out this study.

[5] Farm Accountancy Data Network

Figure 1: The general architecture of the model



3.2 The objective function

The objective is to maximise the incomes of the whole chains of bio-fuels, i.e. the agriculture income and the industrial income, stemming from the sale of co-products and bio-fuels.

$$\underset{\{X_f\}_{f\in F}}{MAX}\left(\sum_{f\in F}\left({}^t\mathrm{M}_f.X_f\right)-{}^t\Theta.C+{}^t(P+S)V+{}^tP'.W\right)$$

$$s.t.\left\{\begin{array}{c} A^{(1)}.X_1 \le B_1 \\ \vdots \\ \vdots \\ A^{(f)}.X_f \le B_f \\ \vdots \\ \vdots \\ A^{(F)}.X_F \le B_F \end{array}\right\} agriculture$$

$$and\left\{\begin{array}{c} \forall e\in E, \sum_{f\in F}\left(x_{f,e}+\overline{x_{f,e}}\right)\cdot y_{f,e} \ge \Theta_e \\ \forall(e,k)\in E\times K, \Theta_e\cdot\Phi_{e\to k} \ge V_{e\times k} \\ \forall(e,h)\in E\times H, \Theta_e\cdot\Phi'_{e\to h} \ge W_{e\times h} \end{array}\right\} industry$$

P, S *and* V are the vectors of R^3 that respectively contain the market prices, the State subsidies and the quantities of the 3 bio-fuels[6]. P' *and* W are the vectors of R^3 that respectively contain the market prices and the quantity of co-products[7]. We denote by *K* the set of the different bio-fuels and by *H* the set of the co-products.

$K = \{RME, ethanol, ETBE\}$ and $H = \{glycerin, cattle\ cake, DDGS\}$

Θ contains the quantity of agricultural raw materials (in tons), while *C* is the vector with the associated variable transformation costs in euros/t.

Now, we detail the constraints that apply to both stages of the model.

3.3 The agricultural constraints

While the model is basically used in order to determine variables concerning energy crops and more widely bio-fuels, we must stress on its taking root in a coherent and complete agricultural model: besides energy crops, a whole set of crops are grown. The model takes into account all the constraints that apply to the "classical" agricultural production, in each and every farm.

For all *f*, X_f is the vector of R_+^C containing the areas dedicated to each crop $\{x_c\}_{c\in[|1,C|]}$, while M_f is the vector of R^C containing the gross margins related to each crop $\{\mu_c\}_{c\in[|1,C|]}$

The matrix $A^{(f)}$ gathers together all the agronomic constraints applying to farm *f*..

$$\forall f \in [|1,F|], A^{(f)} = \begin{pmatrix} a_{1,1}^{(f)} & \cdots & \cdots & \cdots & a_{1,c}^{(f)} & \cdots & \cdots & \cdots & a_{1,C}^{(f)} \\ \vdots & \ddots & & & & & & & \vdots \\ \vdots & & \ddots & & & & & & \vdots \\ \vdots & & & \ddots & & & & & \vdots \\ \vdots & & & & a_{k,c}^{(f)} & & & & \vdots \\ \vdots & & & & & \ddots & & & \vdots \\ \vdots & & & & & & \ddots & & \vdots \\ \vdots & & & & & & & \ddots & \vdots \\ a_{K,1}^{(f)} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & a_{K,C}^{(f)} \end{pmatrix}$$

Each row $ROW_k, k \in [|1,K|]$ contains the technical coefficients related to constraint k.

Each column $COL_c, c \in [|1,C|]$ contains the technical coefficients related to the crop c.

B_f is the vector of R^K containing the upper bounds of the constraints in farm f.

The different crops are as shown below:

[6] The prices of bio-fuels are: 30€/hl for RME, 24€/hl for ETBE and 18€/hl for ethanol (which has an inferior calorific power). These prices correspond to oil prices at 40€/bl (with 1€=$1.2).

[7] The prices of co-products are as follows: 260€/t for glycerine, 125€/t for cattle cakes, 90€/t for DDGS.

$$\{C\}=\left\{\begin{array}{l}\text{barley, wheat, industrial wheat, industrial wheat on set - aside land ,}\\ \text{rapeseed, industrial rapeseed, industrial rapeseed on set - aside land,}\\ \text{winter barley and spring barley, sunflower, industrial sunflower,}\\ \text{industrial sunflower on set - aside land, field bean, peas, sugarbeet,}\\ \text{industrial sugarbeet, industrial sugarbeet on set - aside land}\end{array}\right\}$$

We denote by E the subset of C containing the energy crops.

$$\{E\}=\left\{\begin{array}{l}\text{industrial wheat, industrial wheat on set - aside land ,}\\ \text{industrial rapeseed, industrial rapeseed on set - aside land,}\\ \text{industrial sugarbeet, industrial sugarbeet on set - aside land}\end{array}\right\}$$

3.4 The industrial constraints

Constraints of the raw-material supply

In order to meet the demand for bio-fuels, the agricultural raw materials must be produced in the elementary farms. The subsequent constraint fulfills this requirement.

For all e, $\sum_{f\in F}\left(x_{f,e}+x_{f,\bar{e}}\right)\cdot y_{f,e}\geq\Theta_e$ (1)

Where Θ_e is the supply of the energy crop e in tons and $y_{f,e}$ is the yield in tons per hectare of energy crop e in farm f. $x_{f,\bar{e}}$ (respectively $x_{f,e}$) is the area dedicated to energy crop e in farm f on set-aside land (respectively on land for food crops).

Constraints of the industrial transformation of bio-fuels

Once produced by the scattered farms of the panel, the energy crops are then transformed into bio-fuels in a few plants.

For all $(e,k)\in E\times K$, $\Theta_e\cdot\Phi_{e\to k}\geq V_{e\times k}$ (2)

Where $\Phi_{e\to k}$ is the technical coefficient of the transformation of energy crop e into bio-fuel k and $V_{e\times k}$ represents the sales of bio-fuel k.

This production of bio-fuels also brings various co-products. Their production is set by the subsequent constraint:

For all $(e,h)\in E\times H$, $\Theta_e\cdot\Phi'_{e\to h}\geq W_{e\times h}$ (3)

Where $\Phi'_{e\to h}$ is the technical coefficient of the transformation of energy crop e into by-product h and $W_{e\times h}$ is the quantity of by-product h from energy crop e that is being sold.

3.5 The hypothesis of demand to comply with the European Directive

This study is aimed at assessing the bio-fuels' costs by year 2010, the 5.75% incorporating level being met.

The national demand for bio-fuels (and subsequently for energy crops) so as to meet these commitments has been estimated.

	Production by 2010 (in hl)	Forecasted yield of the corresponding crop by 2010 (in tons/ha)	Agricultural area required in 2010 (in ha)
Wheat ethanol	2,800,000	8.6	91,000
Sugar-beet ethanol	7,200,000	75.1	96,000
Rape-seed Methyl Ester	30,000,000	3.72	1,800,000

Table 1: Bio-fuel production in France by 2010 pursuant to Directive 2003/30/CE (data: French Ministry of Agriculture)

These figures clearly show that the mandatory set-aside land (1,500,000 ha in France) wouldn't be enough to meet the whole quantity of energy crops. Therefore, the opportunity costs of the agricultural raw material (especially rape-seed) will rise sharply, close to the levels of food crops.

What's more, these figures postulate that the equilibrium between the different energy crops is left unchanged by the increase of demand. This constraint has been relaxed concerning the ratio between wheat and sugar-beet (see Tréguer, 2004), without significant variations of the agricultural opportunity costs. Concerning the balance between the two chains of bio-fuels (ethanol vs RME), political considerations may lead to think that the equilibrium is stable.

3.6 Origin of the data

The panel of farms was chosen so as to generate the national supply of agricultural raw material for bio-fuels. Thus, the 20 French continental regions were each represented in the model[8] by a certain number of farms taken in the FADN. In order to derive the variable costs per crop from the FADN data, we used a small LP model that we have detailed in the appendix.

The main asset of such a panel lies in the national representation thus enabled. Moreover, it is therefore possible to derive the regional production of the agricultural raw material for bio-fuels. This possibility could be relevant when addressing issues linked to the distributive aspects of the tax exemptions agreed by the State.

It's also important to stress on that the model is used in order to determine the optimal mapping of energy crops on the French territory. A more realistic approach would consist in laying down a maximum output of energy crops per farm: so doing, a second-best result with higher opportunity costs would be derived. However, this article is simply aimed at deciding on the minimal tax exemption to be set, so as to reach a given level of demand for bio-fuels.

3.7 The different ways to use the model

The model can be either demand- or price-driven:

- Given a demand scenario for bio-fuels, we derive the opportunity cost of the various bio-fuels. This opportunity cost generally proves higher than the market price. Therefore, a minimal incentive must be set, i.e. a reduced tax applied to bio-fuels. It should be stressed on that the agricultural raw materials (as far as energy crops are concerned) are "sold" to the industry at their marginal cost.

- Another way of running the model is to give a market price to energy crops and derive the total quantity of energy crops produced in all the farms. This approach proves relevant to focus on the agricultural phase of the bio-fuels' production, in order to study (i) the

[8] only cereal-oriented and sugar-beet farms were chosen, farms with cattle were excluded

competition between energy crops, (ii) the substitutions between energy crops and their food counterparts, and of course (iii) the variations in surpluses.[9]

4 The results concerning the agricultural costs

4.1 The competition between energy crops

The production of energy crops is highly correlated since such crops compete in a given farm for the allocation of set-aside land. This competition applies for two couples: rape-seed/sugar-beet and rape-seed/wheat.

It is therefore tempting to change parameters related to energy crops (prices or quantities) **simultaneously**.

Let ener1, ener2 and ener3 be three energy crops, namely rape-seed, wheat and sugar-beet.

Their respective prices will vary simultaneously in the model, which will give in return the aggregated quantities of energy crops produced by all the farms in the sample.

All other data in the model remains the same (in particular, the prices of the corresponding food crops[10]).

Let $\{p_i^{ener1}\}_{i\in I}, \{p_j^{ener2}\}_{j\in J}$ $and\{p_k^{ener3}\}_{k\in K}$ be the sets of prices of the given energy crops, with $I = J = K = [\![1, n]\!]$.

Taking simultaneously into account the three sets of prices leads to high computation time lapse.

It has therefore been chosen to change two prices at a time, the third being maintained even.

For each couple (i, j) of prices, the model has been applied. This procedure is carried out for two distinct prices of the third energy crop (here: sugar-beet): $\{p_\alpha^{ener3}, p_\beta^{ener3}\}$

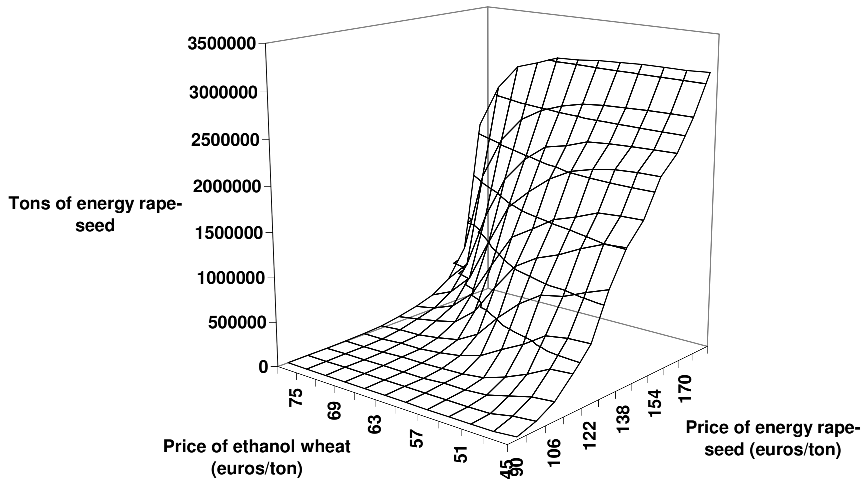
The figure below tends to prove that the two bio-fuel chains' transformation plants are not competing only for public money. They also face a remote competition as far as agricultural raw material supply is concerned. The changes in price concerning the energy crop of the other chain may deeply affect the agricultural cost for a transformation plant.

We observe in this respect that for a given price for energy rape-seed, the total quantity of energy rape-seed produced greatly varies with the price of ethanol wheat (the price levels are such that the energy crops can only be produced on set-aside land).

[9] Other possibilities of running the model could be addressed, such as finding the optimal equilibrium between bio-fuel chains (RME and ethanol) so as to meet the 5.75% objective, while minimizing the costs.

[10] We assume that the energy crops have no impact on food crops' prices, which could nevertheless be subject to further discussions.

Figure 2: Energy rape-seed production, in year 2006, function of two prices



4.2 Competition between food and energy crops

Growing energy crops on set-aside land was a way of avoiding any competition between food and non-food crops. In addition, the transformation plants could receive low-priced agricultural raw materials to be transformed into bio-fuels. As far as France is concerned, the production planned for 2010 so as to reach the European commitments will need some extra land outside the mandatory set-aside. Thus, the formerly low-cost raw materials will compete with their food counterparts. The opportunity costs will then be at levels close to the market price of their food corresponding crop.

Mainly, such an overflow is awaited for rape-seed. The mandatory French set-aside land roughly amounts to 1,500,000 hectares. Complying with the EU Directive would mean an 8-fold increase of the surface dedicated to this crop[11]. It is therefore difficult to avoid a production overflow.

This problem is very acute as far as rape-seed[12] is concerned, since the yields are low compared to the energy crops used for ethanol.

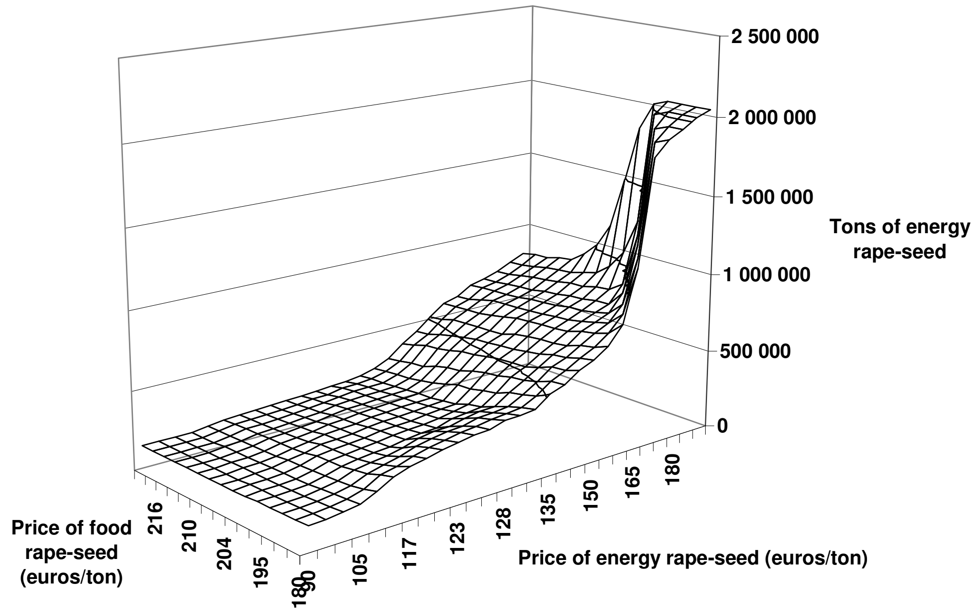
A high demand for energy rape-seed will inevitably bring about a fierce competition between alimentary rape-seed and industrial rape-seed outside the set-aside land.

Two main consequences will derive: First, the opportunity cost for energy rape-seed will rise at levels close to the food rape-seed price. Second, the production of rape-seed for food purposes will decrease.

The figure below shows the high correlation between rape-seed prices and the production of energy rape-seed.

[11] In 2005, the total area dedicated to energy rape-seed will approximately reach 330,000 hectares.
[12] The other possible raw materials for Vegetal Oil Methyl Ester namely sunflower also suffers from low yields.

Figure 3: Energy rape-seed production, in year 2006, function of its own price and the alimentary rape-seed price.



5 Assessing the total costs of bio-fuels

The industrial phase of the bio-fuels' production is marked by uncertainty all the way long.

First of all, the State's decision as far as subsidies are concerned is subject to annual variations. No plant could be constructed without a clear horizon of the levels of tax exemption and the quantity granted with this measure.

Secondly, the bio-fuel chains' profitability will depend on prices volatility in the markets upstream (energy crops, but also food crops as there is a competition between food and non-food crops) and downstream (the highly volatile oil products market but also the co-products markets, the reaction of which to high levels of supply is totally unknown).

In the literature, a Monte-Carlo simulation has been implemented in a mathematical programming framework (French bio-fuel system partial equilibrium analysis) taking into account petroleum price fluctuations (Rozakis and Sourie, 2005). This analysis resulted in estimating the frequency distribution of biofuel costs and by-product prices, thus implying statistically significant minimal levels of subsidy to assure viability of ethanol and biodiesel chains. Results suggest that tax credits could decrease by 20% without risk of viability for any chain.

Also, the real option pricing approach based on the stochastic price processes of fuels in competition is used in the literature for determining the least-cost choice (in terms of economic welfare and tax payers' interest). The option pricing approach for modelling investment under uncertainty is extended by Tareen et al (2000) to determine the biodiesel stochastic adoption threshold substituting for petroleum diesel. When the stochastic nature of biodiesel and fossil diesel cost is considered, the adoption of biodiesel may come earlier than expected in conditions of certainty.

It therefore seems naive to assert that the bio-fuels costs will follow a virtuous path towards the profitability threshold. So thinking, there would be a misunderstanding between the industrial costs of bio-fuels (which could reasonably decrease thanks to scale effects permitted by large plants) and the opportunity cost of bio-fuels, the evolution of which is far more difficult to foresee.

5.1 The opportunity cost of bio-fuels and the minimal tax exemptions

The opportunity costs of bio-fuels OC_k compared with the bio-fuels market prices P_k enable us to derive the minimum tax exemption δ_k that is necessary to implement so as to reach the demand.

$$\forall k \in K, \delta_k = -(P_k - OC_k)$$

The main objective pursued when assessing the opportunity costs of bio-fuels is to determine the minimal tax exemption to be implemented so as to satisfy the demand.

Should the objectives be met by 2010, the resulting minimal tax exemptions would be as shown below[13]:

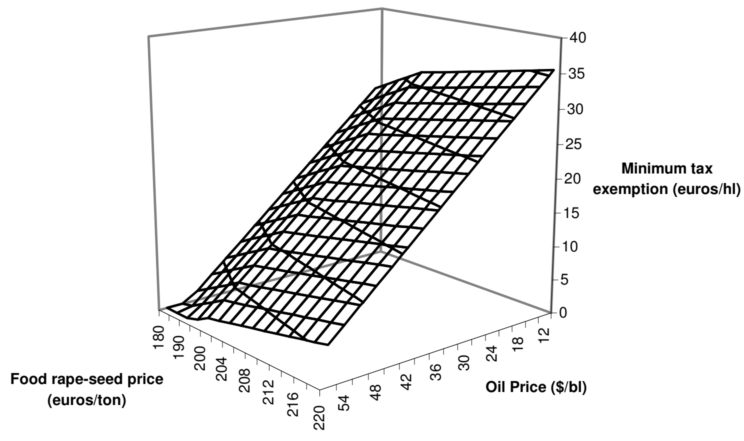
Bio-fuel	RME	Wheat ethanol	Sugar-beet ethanol	Wheat ETBE	Sugar-beet ETBE
Opportunity cost (€/hl)	48.2	36	35.8	33.9	33.7
Price (€/hl)	30	18	18	24	24
Minimum tax exemptions (€/hl)	**18.2**	**18**	**17.8**	**9.9 (which corresponds to 22.2€/hl of ethanol)**	**9.7 (which corresponds to 21.8€/hl of ethanol)**
Real tax exemptions (€/hl), as of 2005	33	37	37	38	38

Table 2: Main Results

These results are not aimed at suggesting what the "right" tax exemption ought to be. It simply intends to shed light on the number of parameters that interact so as to determine the level of exemption. Therefore, a rigid level given for a long time period would tend to contradict this whole complexity.

[13] Of course, these results highly depend on hypotheses on prices and costs. Here, we assume the existence of big transforming units (3000 hl/day, not existing as of today) as far as wheat ethanol is concerned. The transforming unit sizes for sugar-beet ethanol and for RME are those of the existing ones. Oil Price was set at 40€/bl, the exchange rate at 1€=1.2$. We have also postulated an infinite elasticity of demand for co-products (the prices were maintained at today's levels).

Figure 4: Minimum tax exemption needed for Biodiesel (RME), in year 2006, function of oil price and food rape-seed price



This graphic tends to sum up the large range inside which the minimum tax exemption for RME might vary, considering two parameters: oil and food rape-seed prices. Should the first price be low and the latter be high, a non-exemption scheme might be conceivable. In any other case, RME will need subsidies (or another form of incentive), always lower than the actual tax exemption (33€/hl).

5.2 Bio-fuels and CO_2 mitigation

The main asset of bio-fuels lies in their positive externality regarding CO_2 emissions. In the search for levies to reduce GHG emissions, bio-fuels represent a solution that should be carefully considered.

The quantity of CO_2 saved thanks to the replacement of fossil fuels by bio-fuels is given in the table below:

	Tons of CO_2 saved per ton of bio-fuel	Tons of CO_2 saved per hl of bio-fuel
RME	2.2	0.19
ETBE [14]	0.66	0.052
Ethanol	1.40	0.11

Table 3: CO_2 cuts permitted by bio-fuels (Origin of the data: ADEME, French Environmental Agency)

Nearly 7 Million tons of CO_2 could be saved thanks to bio-fuels replacing 5.75% of the fossil fuels by year 2010.

However, if the only CO_2 positive externality is taken into consideration, the present exemption levels would mean that a ton of CO_2 saved is worth 173€ by replacing fossil fuel with RME and 330€ by ethanol. The actual price of 20€/t of CO_2 suggests that bio-fuels ought to have other assets.

[14] The weaker value for ETBE stems from the blending of ethanol (renewable energy) with isobutene (fossil energy).

6 Conclusion

After sorting out the different notions of costs, the concept of opportunity cost has been chosen.

Then, an assessment of the agricultural and total costs of bio-fuels has been carried out using a linear programming tool, which extensively develops the agricultural phase of the bio-fuels' production. Having evaluated the costs of the different bio-fuels and considered the prices that bio-fuels may reach on the market, we have derived a minimal tax exemption that could bridge the gap between costs and prices. The levels we found are higher than the actual exemptions levels.

The production of bio-fuels will reach a significant level in France only if a high-levelled and long-lasting public support (which need not be a tax exemption) is implemented.

However, bio-fuel chains' profitability depends on determinants that have to be analysed on global markets:

- As far as agricultural raw materials are concerned, a remote competition is taking place between world food markets and national energy crops markets. The example of rape-seed is the one that suits best for this purpose. It is likely that the quantities needed to supply the transformation plants are such that the set-aside land is not sufficient. The marginal quantity of energy rape-seed so as to meet the demand will be cropped in competition with the food rape-seed. If the rape-seed world price takes off, so will the costs for agricultural raw material to produce biodiesel. The gains on industrial costs would then be annihilated by the rise of agricultural costs (which account to 66% of the total RME costs).

- At the other extremity of the bio-fuels chains, the oil market has to be considered carefully when dealing with bio-fuels prices. The higher the oil prices, the lesser the bio-fuel chains have to be subsidised (as the bio-fuels' prices are very close to oil prices).

Furthermore, perturbations on the animal food markets (brought about by a huge supply of co-products: glycerine, cattle cakes and DDGS) could damage the benefits permitted by the sales of this valuable component.

As it can be observed, the question of bio-fuels still requires an intensive economic research. Being an issue at crossroads between agriculture, energy and environment, bio-fuels cannot be addressed without taking a wide array of parameters into account.

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