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Abstract: The arable farm sector and biofuel industry models have been coupled to build up a descriptive modelling approach of the biofuel system in France. This approach is based on micro-economic theory principles and is put into practice by means of mathematical programming. The arable farm sector which cultivates dedicated energy crops, is represented by a large number of farms, and the biofuel industry is divided into two main chains; namely, ETBE and bio-diesel, each of which has an intermediate stage (ethanol and seed-oil production, respectively) and a final transformation stage integrated into the petroleum refinery system. The variables, in the model, are the energy crops (wheat, sugarbeet and rape-seed) and the biofuel (ether and ester) activity levels. Goverment allocates an earmarked budget for biofuels through tax exemptions per unit. The model enables the analyst not only to estimate biofuel opportunity costs for fixed individual biofuel quantities and unitary tax exemption levels but also to allocate optimal quantities to each biofuel chain, thus maximising the global surplus of the activity. The results obtained indicate that the French biofuel system could operate with lower levels of tax exemptions for both biofuels, implying that, at the present time, excess surpluses are realised by the agents and particularly the industry.

Keywords: Mathematical programming, Biofuels, Tax exemption, Producer surplus, France.

Introduction

The liquid bio-fuel production (ethanol and methyl esters) take-off that has occured in the last decade has placed Europe, currently representing 6% of the world volume, third behind Brasil and the U.S.A (O.E.C.D.). Biofuel production has reached a significant level in France, where more than half of the total European production of ethanol and methyl esters is produced. The basis of 'green fuels', such as the early sugarbeet-ethanol fueled engines introduction in 1892 in France and the brand new motor launched in the same year by Rudolph Diesel, was the burning of animal or vegetable fat substances. A diesel engine fueled by groundnut oil was exhibited in the Paris World Fair in 1900 and, until the aftermath of the second world war, biofuels were extensively used in Europe (mostly ethanol) and in other regions (for example, palm and cotton oil in Africa). Biofuels had almost completely disappeared by the sixties because of the abundant supply of cheap fossil fuels. However, after the consecutive oil shocks of 1973 and 1979, interest in them saw a revival. The French bio-fuel program was launched in 1993 with the introduction of a tax exemption for bio-fuels[1] following fuel supply uncertainty and environmental concerns. Set aside land obligations introduced in the revised Common Agricultural Policy (CAP) of 1992, which aimed at controlling the over-production of cereals, created a favourable environment for growing non-food crops[2] and was the decisive factor that incited farmers to produce energy crops in sufficient quantities to supply the bio-fuel industry. Indeed, energy crops cultivated on set aside land reached 30% of the total set aside land in 1999. Bio-fuels produced in France comprise Rape-seed Methyl Esters (RME) for use in diesel engines and ETBE (ethyl tertio-butyl ether) extracted from wheat and sugar-beet for use in gasoline engines.

[1] Art. 92, Finance law voted by the French parliament in 1992 established tax exemptions from the I.T.P.P. (Interior Tax to Petroleum Products) for bio-fuels set at 35.06 € hl^{-1} for methyl esters and 50.23 FF hl^{-1} for ethanol used in ETBE and provided for production agreements of 3 or 9 years for fixed quantities of bio-fuels.

[2] Art. 32, 1997, Finance law rectified the 1992 law suppressing the obligation of the bio-fuel industry to use energy crops cultivated in land set-aside. However, in practice the supply of energy crops was related to the percentage of arable land obligatorily set-aside.

The total amount of bio-fuels production in France currently represents approximately 536 thousand tons, or 1.5% of the national liquid fuel consumption. The conversion of biomass to bio-fuels is concentrated in a few plants, whereas the agricultural raw material is produced by thousands of farms located in different parts of the country at varying costs.

Table 1. Bio-fuel production in France[3]

Production ETBE in t			Production RME in t		
Plant sites	1998	2002	Plant sites	1999	2002
Feyzin	85	85	Rouen (Haute Normandie)	180	280
Dunkerque	65	65	Compiegne (Oise)	60	60
Gonfreville	70	70	Boussens (Haute Garonne)	33	33
Fos-sur-mer	9		Verdun (Meuse)	33	33
La Mède + Donges		155	Leer (Germany)	10	10
Totals	**230**	**375**		**316**	**416**

In the 1999-2000 cultivation period, a surface area of 320 000 hectares was cultivated, mainly on land set aside, to supply liquid bio-fuel chains. Total production was expected to increase as new agreements would be allocated to the industry by the government by 2002. The production of RME and ETBE was expected to reach 416 and 374 thousand tons, respectively (Table 1).

Seven years after the take-off of the tax exemption program, bio-fuels are still more costly than fossil fuels and the agro-energy industrial activity largely depends on government subsidies for its viability. Earmarked funds for the financing of the tax exemptions reached 210 thousand € in 1999. On the other hand, environmental problems have become more acute and international committments mean that the abatement of Greenhouse Gas (GHG) emissions requires intensified efforts. Given the fact that biofuel substitution for fossil fuels reduces GHG emissions, the question arises as to whether subsidies for bio-fuels can be justified on the grounds that they contribute to a reduction in the greenhouse effect? Even if the recent rise in crude oil prices alleviates the budgetary burden that bio-fuels represent, the question raised by economists concerning the efficient allocation of this amount among bio-fuel chains through tax exemptions to the bio-fuel processors is of primary importance (Sourie, 2000)[4].

The increased importance of the bio-fuel development program in France has stimulated our interest in improving previously used modelling tools to evaluate public policy (Sourie et al., 1997) and in focusing on the decentralised scale in contrast to the content of other recent works on bio-fuel analysis (Costa and Requillart, 2000). In the present study, a micro-economic model of supply chains that includes an agricultural sector model has been developed for this purpose. The latter is used to evaluate Berlin decision impacts on arable cultures in France. It is supplemented by an industry model of French biofuel chains (ETBE from wheat and sugarbeet, rapeseed bio-diesel), and by the demand scheme for products and by-products model in a way that a partial equilibrium model has been formulated. The integrated model is used to analyse several scenarios and policy implications. A micro-economic analysis of biofuel activity is carried out in order to estimate agents' surpluses. The deadweight loss of the activity is calculated against the benefits of reductions in the emissions of greenhouse. Indirect or induced benefits are not considered.

This paper is organised as follows: first, the model is briefly introduced and is followed by a presentation of the main results. Subsequently, the effectiveness of this methodology in esti-

[3] All information on biofuel production in France has been collected using data published in specialised press (AgraValor, europeAgro)

[4] Tax exemption levels are currently under revision by an expert commission (Levy-Couveinhes) upon request of the French government.

mating the welfare impact and in exploring the possibilities to reduce bio-fuel costs in the short and medium term is discussed.

A partial equilibrium model for the economic analysis of bio-fuel chains

A partial equilibrium economic model based on mathematical programming principles(OSCAR[5]) was built in order to assist in the micro and macro-economic analyses of the multi-chain system of the bio-fuel industry. This approach, which models the existing bio-fuel chains in France -sugarbeet and wheat to ETBE, rapeseed to RME - implies the following:

- that a comprehensive and systemic method is required (due to the bio-fuel chains interdependency), not only at the resource production level but also at the output level ,
- that detailed modelling of the agricultural supply is required to take into account the diversity of the arable farming system, agronomic constraints and production techniques (see Sourie, chapter 1).
- that it is possible to proceed to the economic optimization of the whole system and to use multi-criteria methods to assist in policy making[6] .

Each chain consists of five production stages: biomass production, collection, first and second transformation, demand for bio-fuels and by-products.

The model determines:

- the optimal biomass supply and farmers' surplus, given the policy context and agronomic environment
- the opportunity cost of bio-fuels, depending on crop supply, industrial costs and the demand for bio-fuel and by-products,
- the optimal tax exemption allocation to bio-fuel chains and agents' surpluses in different market contexts (monopoly, cartel etc.),
- Biofuel contribution to the reduction in the greenhouse gase emissions, along with the economic cost incurred by society for the different scenarii of budgetary expenses and tax exemption levels. The levels of activity for each chain, the funding required, as well as the aggregate welfare benefit can be determined by maximising biofuel contribution to cope with the greenhouse effect.

The structure of this model allows for consideration of additional chains, such as straw to ETBE. Environmental effects generated by the activity, together with other objectives, can be determined by means of multi-criteria decision-making.

Model specification

The micro-economic model represents the agro-energy chain structure by simulating farmers' behavior with that of industry. It integrates the agricultural sector[7] and a bio-fuel industry model (in this case, the French multi-chain bio-fuel system) based on mathematical programming principles[8] in order to simultaneously optimise economic surplus. The model proposes a decentralised decision solution based on the agents' behaviour in the respective markets. When industrial capacity is a continuous variable, OSCAR is an LP, otherwise it becomes an MILP bi-level model[9] (Williams, 1985); its generic mathematical form is specified below.

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[5] OSCAR: «Optimisation du Surplus économique des Carburants Agricoles Renouvelables»

[6] A Decision Support Tool was applied to biofuels (Rozakis *et al.*, 2001) and to bio-electricity (Varela *et al.*, 2001).

[7] Optimization model with a matrix of technical coefficients of 7500x6800. The agricultural sector component aggregates 700 elementary arable farm models located in sugarbeet and cereal production regions.

[8] Models are written in GAMS code (Brooke *et al.*, 1998).

[9] An equivalent model of the bio-fuel energy system assigning transformation units of fixed capacities using discrete variables is presented in Chapter 1 of this volume by Mavrotas *et al.*.

Indices and variables

e	farm indices
w	relative weight of each farm in the model
al	vector of food crop surface in ha
ja	vector of set aside land surface in ha
nal	vector of food crop surfaces in ha
tr	vector of variable quantities of energy crops transformed to bio-fuels in t
vt	vector of bio-fuel quantities in t
vc	vector of co-product quantities in t

Coefficient matrices
(Technical parameters used are presented in Table 7, Appendix)

A	sub-matrix of technical agricultural production coefficients
R	sub-matrix of non-food crop yiels in t
T	sub-matrix of conversion coefficients
[I]	unitary matrix
sub	vector of unitary subsidies to bio-fuels

Agricultural sector

$A1_e(al_e, ja_e, nal_e)$	$\leq w_e t_e$	agronomic constraints	**(1)**
$A2_e(al_e, ja_e, nal_e)$	$\leq w_e f_e$	flexibility constraints	**(2)**
$A3_e(al_e)$	$\leq w_e q_e$	market outlets - quotas	**(3)**
$A4_e(ja_e, nal_e)$	$\geq w_e s_e$	set-aside land constraints	**(4)**

Biomass availability, conversion process and bio-fuel demand constraints

$-\sum_e R_e nal_e + [I]\cdot tr$	≤ 0	biomass raw material supply	**(5)**
$- T1\ tr + [I]vt$	≤ 0	bio-fuel supply	**(6)**
$- T2\ tr + [I]vc$	≤ 0	co-product supply	**(7)**
$sub\ .\ vt$	$\leq maxSub$	maximal subsidy to biofuels	**(8)**

Objective function: to maximise global surplus

$$S = \sum_e (ma_e al_e + mja_e ja_e - cnal_e nal_e) - ctr \cdot tr + (pvt + sub)vt + pvc \cdot vc \quad \textbf{(9)}$$

ma	vector of gross margins of food crops FF/ha
mja	vector of gross margins of set aside land FF/ha
cnal	vector of variable costs of non-food crops
ctr	vector of total costs of biomass collection and conversion to bio-fuels
pvt	bio-fuel price vector
sub	subsidies to bio-fuels vector
pvc	co-product price vector

Surplus allocation to farmers and other stakeholders (industry)

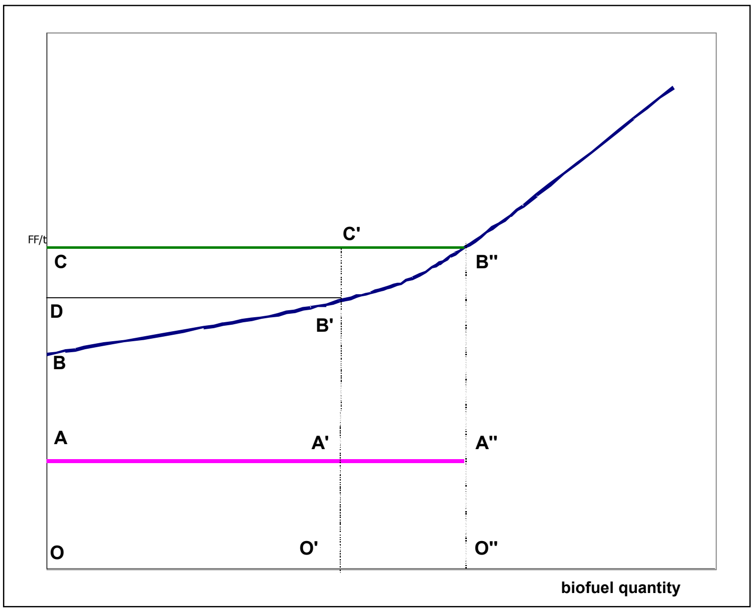

Figure 1. Economic surpluses generated by the bio-fuel production and tax exemption processes

Box 1
Tax exemption to biofuels (no budgetary constraints)

BB´B´´	:	biofuel supply curve=biomasse opportunity cost+conversion cost-coproduct value
OA	:	biofuel market price (perfectly elastic demand curve)
OC	:	biofuel value=biofuel market price + tax exemption (AC)
OO´´	:	quantity produced at the equilibrium level (biofuel value equal to its marginal cost)
CBB´´	:	producer (agricultural sector) surplus
CB´´A´´A	:	budget cost to the government of the biofuel support program
ABB´´A´´ = CB´´A´´A - CBB´´	:	deadweight loss

Taking into account exogenously fixed tax exemptions and biofuel demand levels, technical parameters (Table 10, Appendix), the industry's technology level and cost structure[10], as well as the material input cost (based on energy crop supply curves[11]), the agents' surplus can be estimated as shown graphically in Fig. 2. The agent's surplus is maximised by determining activities for both chains, given a maximum fixed amount of government expenditure. Dual prices that correspond to biomass availability constraints (relationship 5) are equal to the opportunity

[10] Transformation costs economies due to technical developments have been taken into account. Industrial cost estimation is based on the opportunity cost of capital higher than the market discount rate. Industrial units are assumed to be homogeneous having the same costs. Capacities are considered continuous variables, thus economies of scale are not taken into account in this exercise.

[11] As price discrimination is not possible, the opportunity cost of the least efficient producer determines the price of the resource; in other words, the cost of the resource for industry. Efficient producers enjoy a surplus. The aggregate surplus is called *agricultural surplus*.

cost of the agricultural resource. If *eff* denotes the marginal value of the total subsidy, it is equal to the dual value of constraint (8). The farmers' surplus or farm income increase due to energy crop production is: *S - eff * maxsub*. The industry surplus is then equal to *eff * maxsub*. If the budgetary constraint is not bound, the global surplus is equal to farmers' surplus. The graph in Figure 1 illustrates the above reasoning in simple form in the case of a single biofuel chain model. When no budgetary constraint exists, the production equilibrium is defined by the intersection of the demand and supply curve; in this case, point B´´. At this point, the produced quantity equals OO´´. The producer's surplus, which in this case coincides with the agricultural surplus, total budget expenses and the deadweight loss of the activity, can be determined graphically as shown below:

Box 2. Case B
Tax exemption of biofuels under budgetary constraint

CC´A´A	:	total budget earmarked to biofuel
OO´	:	biofuel quantity produced (agreements approved by the government that depend on earmarked budget)
CA	:	tax exemption for biofuel (depends on budget)
DBB´	:	producer (agricultural sector) surplus
DCC´B´	:	industrial surplus
ABB´A´ = CC´A´A - DBB´ - DCC´B´ ´	:	deadweight loss

Bio-fuel costs for the horizon 2002

In practice, however, since 1993 when the biofuel activity kicked-off, the government has been engaged in preserving an equilibrium among different chains (for historical and lobbying reasons). Thus, policy-makers would prefer to introduce fixed quantities into the model to produce for all three chains and to examine how much the bill would cost and the surplus level generated for agents involved.

The 2002 horizon selected since further modifications in the CAP are expected to have been made by then. Firstly, the expected 2002 biofuel production levels are introduced into the model as targets to be attained by the system in order to calculate the biomass and bio-fuel costs[12]. Agricultural production is localised to cereal and sugarbeet producing farms in such a way as to minimise total biomass resource costs. The model selects the most efficient farms i.e., the farms that generally attain the highest yields.

Opportunity cost of agricultural resource, yields and cultivated area.

In order to minimize bio-fuel cost, OSCAR localizes production to the most efficient farms. A minimal farm income increase of 76 € ha^{-1} is assumed to constitute an incentive for farmers to cultivate energy crops[13]. Opportunity costs calculated by the model appear in Table 4.

[12] Bio-fuel costs, particularly the biomass agricultural ressource cost, increase with the increase in the quantities produced.

[13] With no incentive, last supplier's (or the less cost-efficient) revenue increase will be too low to compensate for additional labor devoted to the cultivation of non-food crops instead of land set aside.

Table 4. Opportunity costs of resources and average yields

	Yield (t)	€ t^{-1}	Q (kt)	Surface (ha)
Rapeseed	3.9	166.9	1466	246250
Wheat	9	64.8	209	23387
Sugarbeet	82.8	17.7	969	17705

Opportunity costs[14] of rapeseed and wheat are much lower than food crop prices (175-183 € t^{-1} et 99-107 € t^{-1}, respectively). This can be attributed to the fact that rapeseed and wheat for energy are cultivated in land set aside with very low land rent. Active set aside land rate reaches 5%[15]. Sugarbeet costs should be compared with the costs of sugarbeet category C that competes in the world market (around 15.25 € t^{-1} in 1999).

Table 5. Cost of bio-fuels (Source : model OSCAR results for set aside rate of 5%)[16] .

		Resource cost*	Insdustry cost[17]	Co-product sales[18]	Biofuel costs	Bio-fuel value average*	2000**
ETBE wheat	€ l^{-1}	0.08	0.27	-0.06	0.29	0.13	0.27
ETBE sugarbeet	€ l^{-1}	0.08	0.25	0.002	0.32	0.13	0.27
RME	€ l^{-1}	0.37	0.22	-0.19	0.40	0.14	0.25

*average 1992-2000 FOB Rotterdam brent 18,6 per baril,$1 = 0.87 €; source DIMAH

**2000 brent $28,11 per baril

The total surface area to be cultivated in order to satisfy the exogenous demand for bio-fuels is set at 287,300 ha (Table 4). This is clearly lower than the actual surface area cultivated by energy crops, which is due to the high levels of average yields resulting from the optimal localisation of production. In fact, the surface area harvested in 2000 reached 320,000 ha, despite the fact that actual approved amount was only 536,500 t[19]. The model selects 58,800 arable farms, i.e. 72% of the 81,000 farms with the potential to participate in the bio-fuel program. Each farm cultivates 4 ha of energy crops on average. If the producers' price are equal to the opportunity cost (Table 4), there is an approximate 900 € increase in income per farm. The costs of biofuels are quite different, ester costs being higher than those of ETBE (Table 5). The direct costs of ETBE are 2.2-2.4 times higher than unleaded gasoline costs, whereas RME costs are 2.9 times more expensive than those for diesel fuel. These ratios decreased significantly in 2000, when current rates are taken into account, to 1.1 and 1.6, respectively[20].

Costs include farmers' surplus and the economic incentive of 76 € ha^{-1}. Ethanol from wheat is produced in a plant with a 300 m^3 per day capacity. It is a fact that operating units in France actually run at one third of this capacity. The industrial cost of ethanol from sugarbeet takes

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[14] Opportunity costs are equal to the dual values of the biomass availability constraints of the model.

[15] The formal set aside rate is fixed at 10% of the land historically cultivated land with cereals and oil&protein seeds. A 5% rate has been used to take into account fluctuations in the rates revised by Brussels each year, depending on cereal stocks and the international market, as well as on the fixed set aside concerning low fertility marginal land that can be re-cultivated but at too high a cost.

[16] Mass volume ratios 0,75kg dm^{-3} for ETBE; 0,88kg dm^{-3} for RME (Source: Lévy, 1993)

[17] The wheat-to-ethanol study takes into consideration economies of scale for plant capacity of 300 m^3 per day instead of 100 m3 per day (Herbert, 1995). Sugarbeet-to-ethanol costs (mission Levy-Couveinhes Mai 2000, personal communication) are difficult to estimate due to overlappings among the ethanol, alcohol and sugar production processing industries. ETBE costs, Rapeseed Methyl Ester (RME), mission Levy-Couveinhes Mai 2000, personal communication .

[18] Cattle cake prices increased from 91.5 to 130 € t^{-1}, draff prices from 102 to 122 € t^{-1}, whereas glycerine costs fell from 457 to 381 € t^{-1}.

[19] Source: ONIOL

[20] Note that adjustments have also to be made to measure the effect of high oil prices on the bio-fuel production cost.

into account synergies among sugar, alcohol and ethanol industry. On the other hand, ester is produced in an integrated unit similar to the one actually operating in Rouen (120000 t RME/year).

The cost of the agricultural resource is important for RME, which makes the chain sensitive to input cost variations. This cost is partly compensated for by co-product sales. Wheat-to-ETBE chain co-produces DDGS (Distilled Dry Grain Solubles), which are rich in proteins. The co-products of ETBE from sugarbeet (pulp, inferior wine) have a low market value, but their industrial costs are lower than those for ETBE from wheat co-products. The minimal subsidy required for biofuel industries to break even is presented in Table 6. Taking into account the aforementioned hypotheses (only efficient farmers produce), a minimum farm income of 76 € ha^{-1} as an incentive to the less efficient farmers, Table 5 industrial costs, average oil prices and the dollar's average value for the period 1992-2000), differences between the actual and theoretical minimum subsidies vary between 0.07 – 0.14 € l^{-1} (see Table 6).

Table 6. Minimal subsidization of bio-fuels (oil and dollar price averages for 1992-2000)

	Biofuel value		Biofuel cost		Minimum subsidy			Tax exemption
	€ t^{-1}	€ 1^{-1}	€ t^{-1}	€ 1^{-1}	€ t^{-1}*	€ 1^{-1}*	€ 1^{-1}**	€ 1^{-1}**
ETBE wheat	177	0.13	390	0.29	213	0.16	0.36	0.50
ETBE sugarbeet	177	0.13	429	0.32	252	0.19	0.43	0.50
RME	157	0.14	454	0.40	297	0.26	0.26	0.35

*regarding ETBE, chain results figure per t or l of ETBE.

** regarding ETBE, chain results figure per l of ethanol

Induced economic benefit of the agricultural production of biomass for bio-fuels

Farmers' surplus[21] measures the total rent enjoyed by farmers producing at a cost lower than the opportunity cost of the least efficient farmer, as shown in Table 6.

The economic incentive, presented in Table 7, corresponds to the amount of 76 € ha^{-1} given to all farmers. Due to biofuel per hectare yields, this amount is more important for RME than for ETBE[22].

Table 7. Benefit induced by the production of bio-fuel crops in € m^{-3}

	Farmers' surplus	Economic incentive	CAP savings	Total benefits
ETBE wheat	4.42	10.67		15.09
ETBE sugarbeet	4.27	3.96	22.41	30.64
RME	60.22	42.54		102.76

Economies over set aside subsidies exclusively concern sugarbeet to ethanol, since its production for energy reduces the amount of direct aids to the farm[23].

[21] As previously explained, this surplus is generated during the transaction of the agricultural resource between farmers and the bio-fuel industry, due to the fact that industry is not able to differentiate among the prices of energy corps for such a large number of farmers. In order to have a zero surplus, industry should offer each farmer its specific price. This is practically impossible due to the large number of farmers involved in the process.

[22] On the basis of the average yields shown in Table 4, RME production per ha reaches 1.75 m^3, that of wheat-to-ETBE 7.14 m^3, and that of sugarbeet-to-ETBE 18.77 m^3 (0.59 m^3 of ethanol per t ETBE).

[23] Unlike wheat and rapeseed energy crops, sugarbeet for ethanol production does not enjoy any CAP subsidy, which saves the E.U. budget 425 € per ha of sugarbeet cultivated surface.

Globally, induced economic effects are very important in relative terms, especially for the RME chain. The ETBE chain reaps benefit from the set aside subsidies. The wheat-to-ETBE chain generates the least induced economic effects at the agricultural production level.

Discussion on optimal tax exemption levels.

When budget expenses for biofuels are constrained (case B in Box 2), a reduced quantity (*OO´ instead of OO´´*) will be produced and industry will also see a surplus. OSCAR can minimise the aggregate economic cost for the three chain French biofuel systems - for a given demand, agent's surplus is maximised - and determine the optimal production levels, given the fixed amounts of government expenditure and the fixed tax exemption values per unit of biofuel volume. Maximum funding could be approximately equal to the expenses earmarked for the biofuel program for the year 2002 (see introduction), that is, about 210 k€. Parameters regarding unitary tax exemptions are fixed at 27.44 and 38.11 €/hl for bio-diesel and ethanol, respectively. The results are given in Table 8. The solution adopted by the model sets activity levels for ETBE-wheat and RME, not allowing the ETBE-sugarbeet chain to produce. Disaggregate agricultural surplus is shown in Figure 2, with RME chain results giving much higher surpluses for agriculture (scenario I in Table 9).

If agents behaved according to the model's hypotheses, assuming the technical and economic assumptions presented in the previous paragraphs, minimal tax exemptions could be determined and production levels for all biofuel chains proposed, thus optimising for global surplus under budgetary constraint. In other words, the model becomes non-linear as tax exemptions times biofuel volumes (tax credit aggregates) are included in the objective function. If we re-iterate the solution process using different tax exemptions, the model proposes different solutions; for instance, that scenario II (30.5 and 38.1 €/hl for bio-diesel and ethanol, respectively) results in increased economic welfare(last column in Table 9).

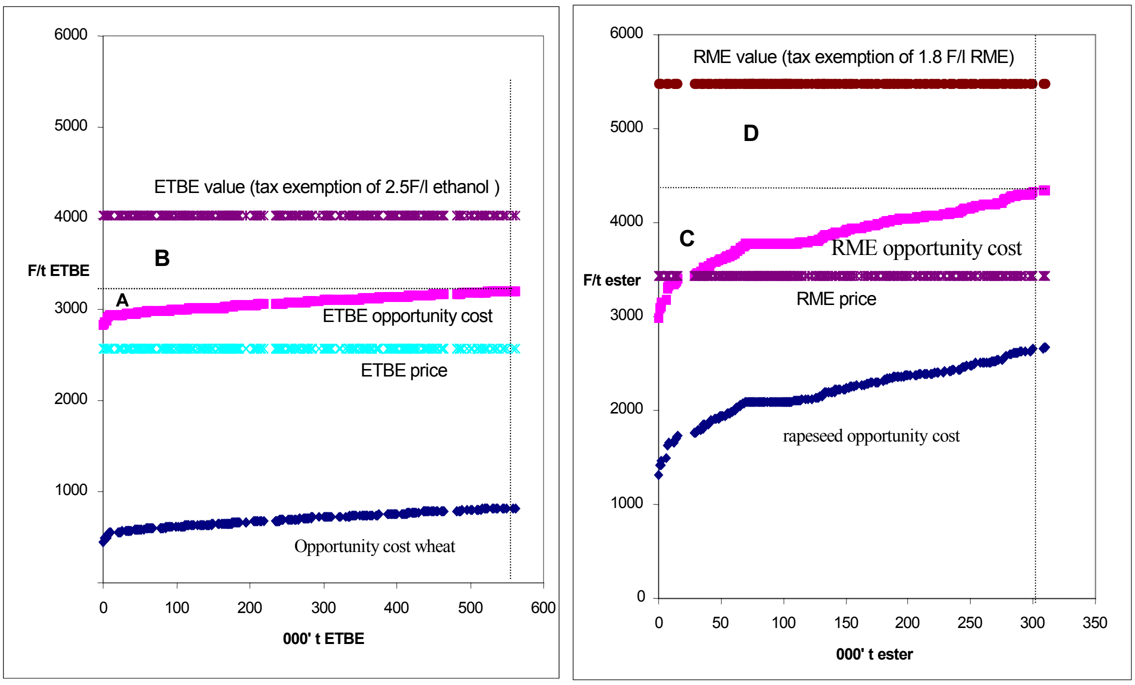

Figure 2. Optimal OSCAR allocation of economic welfare to agents (by biofuel chain).

Table 8. OSCAR model solution (scenario I)

Optimal solution (global surplus maximised)		ETBE	Ester
Unitary tax exemption	€/hl	38.11	27.44
Optimal quantity in t of bio-fuel	000 t	562	310
Value of bio-fuel + tax exemption	€/t	615	836
Value of bio-fuel + co-products	€/t	391	524.4
Bio-fuel cost	€/t	487.5	662.85
Biomass input cost	€/t	124.5	407.3

Table 9. Economic efficiency and agents'surplus

		units	Scenario I	Scenario II
Bio-diesel tax exemption per unit		€/l	0.274	0.305
Ethanol tax exemption per unit		€/l	0.38	0.38
Welfare deadweight loss		M€	68	62.8
Producers' rape-seed surplus	(C)	M€	21.3	28.5
Bio-diesel industry surplus	(D)	M€	53.4	69.8
Wheat producers' surplus	(A)	M€	9.9	7.5
ETBE industry surplus	(B)	M€	69.5	53.8

Conclusions

OSCAR is a partial equilibrium model that allows for micro-economic analysis of the biofuel industry by applying an integrated (chain oriented) and systemic (multi-chain optimisation) approach. It can be used for economic analyses in cases where micro-economic realities are considered, and it is capable of supporting multi-criteria analysis and enviromental economics approaches. The data used in this model are thoroughly detailed and allow for the parameterization of technical and economic coefficients.

The aim of this study was to estimate the micro-economic cost of bio-fuels resulting from the minimisation of agricultural resource production costs, for the year 2002. This minimisation is extremely important for the RME chain because of the agricultural input weight on the total bio-fuel cost. The ETBE cost was estimated to be 0.29-0.32 € l^{-1} and the RME 0.40 € l^{-1}. The optimisation of industrial costs was treated in less detail due to the inadequate amount of information currently available. Although the results obtained here should not lead to premature conclusions about the relative interest of particular chains, minimal subsidy estimations (differentials of costs and values) have been made available, taking into consideration their dependency on oil and dollar prices. They can be justified in the eyes of the taxpayers by the induced economic effects reaped by the farmers (Table 7) and by the positive externalities generated by the biofuel activity.

The partial equilibrium model could be improved with a more detailed representation of the industry. However, the introduction of information into the model concerning diverse plant capacities would complicate the modelling work as it would require the use of integer variables. Nevertheless, the fact that results would be more realistic, incorporating effects of scale, would compensate for this difficulty. Solvers currently available can easily accomodate this kind of model. Mavrotas et al., in this volume, present precisely this aspect in the case of multicriteria optimisation. The main barrier to build more realistic models is the lack of reliable data concerning biofuel industry.

Another issue that distorts biofuel opportunity cost estimation is the assumption of a perfectly elastic demand for the system's by-products especially those sold to the livestock feed market. The multi-market modelling approach porposed by Jayet (Chapter 1 in this volume), which represents the interaction of the agricultural sector model (not including explicitly energy crops) with the animal feed industry sector and the search of price-quantity equilibria could be implemented to enhance the biofuel system partial equilibrium model.

The agricultural resource is produced at the least cost by the most intensive farms, as proposed by OSCAR, which causes a reduction of the surface area required for the cultivation of energy crops. However, since intensive energy crop cultivation involves a higher risk of environmental pollution, the coupling of this micro-economic model with bio-physical models (similar to the ones studied and developed by the INRA research teams; namely CERES and STICS, respectively) could help in dealing with this problem and in examining alternative cultivation techniques destined for scrutiny through economic and ecological lenses.

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Appendix

Table 10. Technical coefficients of the biofuel production activity

Biofuels	Units	ETBE		Ester
		sugarbeet	wheat	rapeseed
Biofuels	t	1	1	1
Biofuels	l	1333.3	1333.3	1136.0
Agric. Resources	t	5.88	1.68	2.50
Ethanol	l	587.85	587.85	
Cakes	t			1.40
DDGS*	t		0.70	
Glycerine	t			0.10

*DDGS : Dry distilled grain solubles