Bio-fuel multi-stage activity modelling to determine efficient public policy in uncertain agricultural markets[♣]

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Abstract

Support policy to biomass-origin liquid fuels incorporated in gasoline and diesel has been implemented during the last decade in France through tax exemptions to bio-fuels. Tax exemption levels as well as production agreements determining beneficial quantities are allocated by the government depending on an earmarked budget revised every year by the parliament.

A partial equilibrium model with a detailed agricultural sector component that is formed by a large number of representative farms producing energy crops (wheat, sugar-beet and rapeseed) jointly with food crops, is used to estimate costs and surpluses generated by the bio-fuel production activity at the national level. The aggregate supply of energy crops is estimated using a staircase model of elementary farm sub-models specialising in arable cropping. The government acts as a leader since bio-fuel chains depend on subsidies. The model provides the industry reaction to policy schemes, taking into account the energy crop producers' supply response curve. A multi-criteria optimisation module can assist the policy maker to select policies that serve budgetary, environmental and social concerns by approaching decision-maker's objectives at the closest feasible compromise levels.

In order to enhance the predictive ability of such a model, interval linear programming (ILP) is used to consider uncertainty related to yields and prices and its impact to the farmer behaviour. Besides the expected gross margin maximisation rationale, the distance from optimality once uncertainty resolves (maximum regret) is a useful criterion that farmers apply in many cases. A hybrid mathematical programming model is then set up articulating custom utility functions for each individual farmer according to observed behaviour and the specific properties of each farm. Energy crop supply curves generated by the hybrid model proved to be slightly deplaced to the right (less costly energy crops) but still upward sloped.

Keywords : *Partial equilibrium model, Liquid bio-fuels, Tax exemption policy, Interval Linear Programming, Minmax Regret, Multicriteria Analysis*

JEL codes: *C61, D81, H23, Q12, Q42*

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1. 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. 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

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[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.

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

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 commitments 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 [28][4].

In the present study, a micro-economic model of supply chains that includes an agricultural sector model has been developed for this purpose. 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 [27] and in focusing on the decentralised scale in contrast to the content of other recent works on bio-fuel analysis [5]. Thus, the model is specified as a staircase linear program (LP), corresponding to a representative sample of farms, that can capture the diversity of the sector and predict quite accurately policy impacts regional level, provided that they adequately articulate the goals and the constraints of individual farms. Usually, such aggregate models suppose that every farmer intends to maximize expected gross margin. This hypothesis however seems hardly justifiable, especially, when we consider the actual gross margin variability due to the agricultural policy changes. The uncertainty about crop prices and yields may have the farmers to experience regret reflecting on how much better his position would have been, had he chosen differently. Then farm models whom observed behavior is explained better when uncertainty is taken into account, in other words for those farmers that minmax regret objective function reproduces results closer to the base year 2002 crop mix, are hereafter using the ILP specification. When gross margin maximisation rule reproduces satisfactorily reality it is retained as a decision rule and those individual farm models remain LP specified. Thus, a hybrid staircase arable cropping model is formed with an improved predictive ability that the initial LP. The main drawback is the exponential increase of computing time lapse when interval coefficients in the objective function increase. This issue is discussed in section 4 where relevant technical information is given.

The agricultural sector module is supplemented by an industry model of French biofuel chains (ETBE from wheat and sugar-beet, rape-seed 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

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

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.

Finally a methodology that integrates social, economic and environmental facets of rationality is applied to evaluate public policy and estimate efficiency of subsidies on environmental grounds. For this purpose the multi-criteria analysis (MC), namely the reference point method, is used to assist policy makers to explore the feasible set in search of efficient solutions approaching the best their (conflicting) objectives. This approach implies that environmental effects need not be expressed in monetary costs or benefits. Instead, it is proposed to proceed using physical units. An MC algorithm coupled with the micro-economic bi-level model assists in this endeavour. The model is illustrated for the French bio-fuel industry of wheat-to-ethanol and rape-seed-to-ester chains.

This paper is organised as follows: first, the basic LP model is briefly introduced and main results are presented and possibilities to reduce bio-fuel costs in the short and medium term is discussed. Subsequently, the limits of LP optimisation and the effectiveness of this methodology in estimating activity levels and related costs as well as the welfare impact of public policy is questioned. Uncertainty over profits requires recourse in bounded rationality and regret theory alternative is examined in section 3. Formal aspects of the "Interval Linear Programming (ILP)" approach are summarized and the use of the min-max regret criterion within the ILP framework is then presented. The implementation procedure and results thereof are the focus points of section 4. In the last section, the decision support methodology is proposed that integrates multiple criteria, and the decision making process is simulated through illustrative examples, followed by some conclusions.

2. 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 –sugar-beet 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,
- 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.

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

Each chain consists of five production stages : biomass production, collection, first and second transformation, demand for bio-fuels and by-products. The structure of this model allows for consideration of additional chains, such as straw to ETBE. 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.

2.1 Model specification

The micro-economic model represents the agro-energy chain structure by simulating farmers' behaviour with that of industry. It integrates the agricultural sector[6] and a bio-fuel industry model (in this case, the French multi-chain bio-fuel system) based on mathematical programming principles[7] 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 [37][8]; its generic mathematical form is specified below:

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

$$A1_e(al_e, ja_e, nal_e) \le w_e t_e \qquad \text{agronomic constraints} \qquad (1)$$

$$A2_e(al_e, ja_e, nal_e) \le w_e f_e \qquad \text{flexibility constraints} \qquad (2)$$

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[6] Optimization model with a matrix of technical coefficients of 7500x6800. The agricultural sector component aggregates about 680 elementary arable farm models located in sugarbeet and cereal production regions.

[7] Models are written in GAMS code [3].

[8] An equivalent model of the bio-fuel energy system assigning transformation units of fixed capacities using discrete variables is presented by Mavrotas&Rozakis [19].

$A3_e(al_e) \leq w_e q_e$ 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

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

Objective function: to maximise global surplus

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

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)

Dual prices that correspond to biomass availability constraints (relationship 5) are equal to the opportunity 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 1. Case A :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

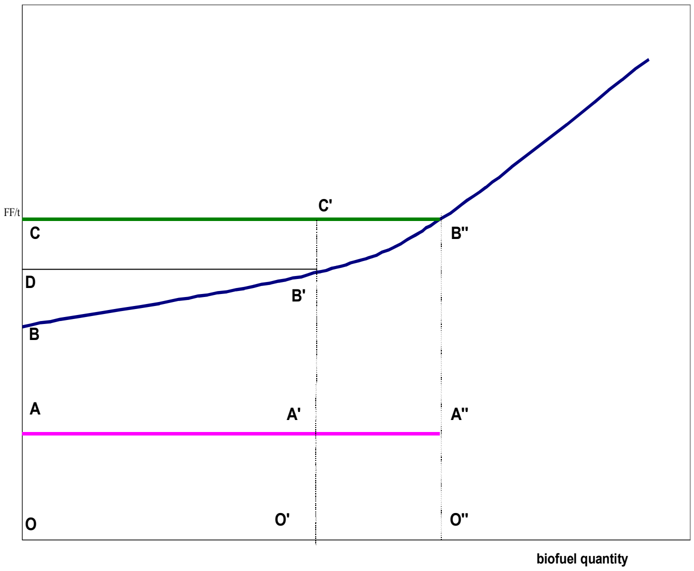

Figure 1. Economic surpluses generated by the bio-fuel production and tax exemption processes

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

Taking into account exogenously fixed tax exemptions and biofuel demand levels, technical parameters, the industry's technology level and cost structure[9], as well as the material input cost (based on energy crop supply curves[10]), 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.

2.2 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

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[9] 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.

[10] 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*.

system in order to calculate the biomass and bio-fuel costs[11]. 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[12]. Opportunity costs calculated by the model appear in Table 2.

Table 2. 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[13] 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% [14]. 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).

The total surface area to be cultivated in order to satisfy the exogenous demand for bio-fuels is set at 287,300 ha (Table 2). 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[15]. 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 2), 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 3). 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[16].

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 sugar-beet takes into account synergies among sugar, alcohol and

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

[12] 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.

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

[14] 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.

[15] Source :ONIOL (Professional Association of Oilseed producers)

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

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).

Table 3. Cost of bio-fuels (Source : model OSCAR results for set aside rate of 5%)[17].

		resource cost*	Insdustry cost[18]	Co-product sales[19]	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 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 4. 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 4).

Table 4. Minimal subsidization of bio-fuels (oil and dollar price averages for 1992-2000)

	Biofuel value		Biofuel cost		Minimum subsidy			Tax exemption
	€ t^{-1}	€ l^{-1}	€ t^{-1}	€ l^{-1}	€ t^{-1}*	€ l^{-1}*	€ l^{-1}**	€ l^{-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[20] 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 4.

The economic incentive, presented in Table 5, 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[21].

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[17] Mass volume ratios 0,75kg dm^{-3} for ETBE ; 0,88kg dm^{-3} for RME

[18] The wheat-to-ethanol study takes into consideration economies of scale for plant capacity of 300 m^3 per day instead of 100 m^3 per day. 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.

[19] 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}.

[20] 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.

Economies over set aside subsidies exclusively concern sugarbeet to ethanol, since its production for energy reduces the amount of direct aids to the farm[22].

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.

Table 5. 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

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 2004 (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 2. 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 7).

Table 6. 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

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[21] 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).

[22] 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.

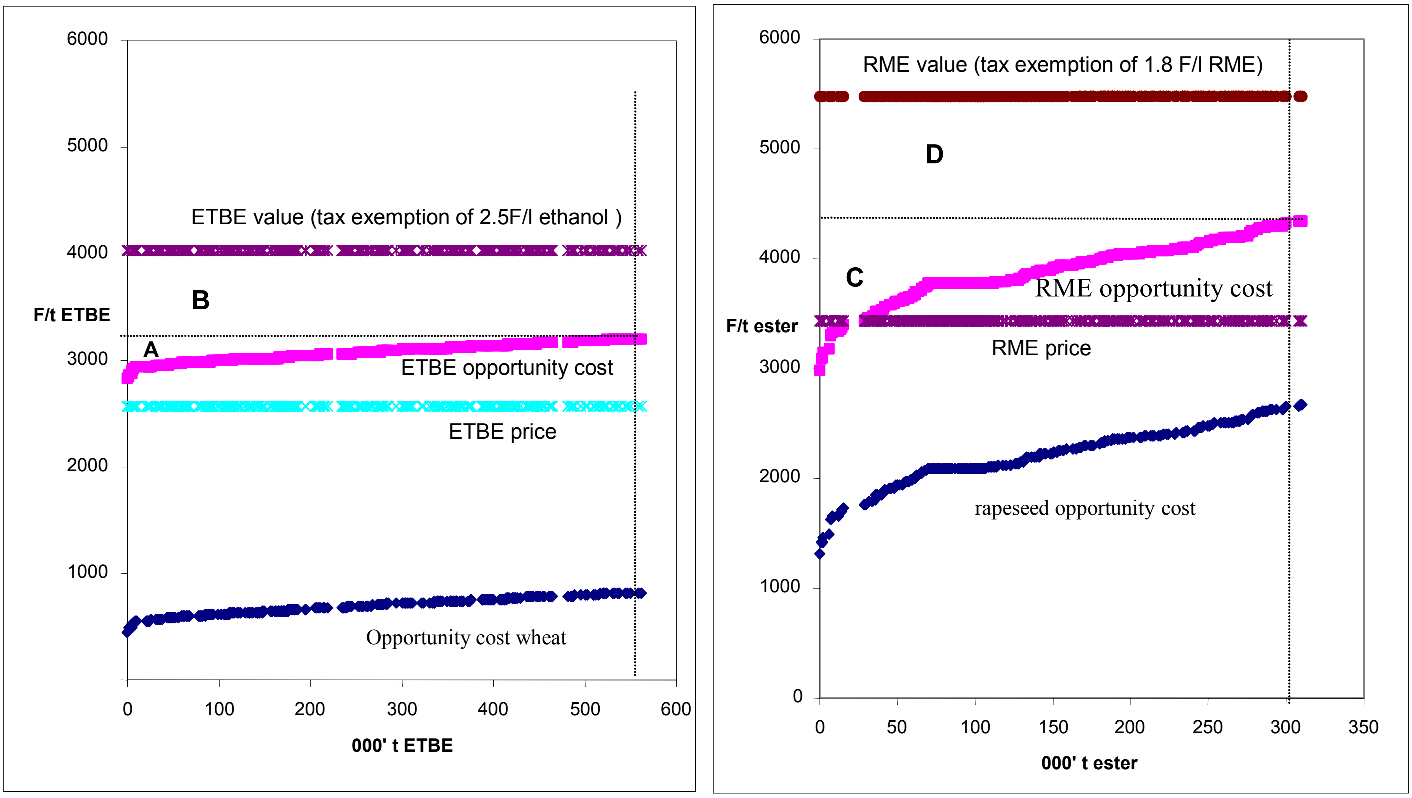

Figure 2. Optimal OSCAR allocation of economic welfare to agents (by biofuel chain).

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 7).

Table 7. 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

3. Uncertainty at the farm level, LP limits and Interval Linear Programming

Marthematical programming representations of arable agriculture supply featuring the integration of farm-level decisions with regional aggregates, convey to the policy makers community the dynamics of the agricultural sector [29]. A farm-based model is explicitly a normative or prescriptive tool at an elementary level; the farmer specifies his decision rule and the model simulates the consequences of that decision rule given the constraint structure, in other words, the feasible activity plans. On the other hand in a decentralised economy there is no single decision maker at the sector level. There are multiple levels of decision, namely, farmers, industry and the policy makers, whose interest do not generally coincide. A model that can explain producers' reactions (farmers and industry) to exogenous signals (prices, government policy) can be normative regarding the policy part, but generally speaking it is a descriptive or positive model. This model can inform policy makers on producers decisions under different policy scenarii. There are two distinct stages in the exploitation of such a model. The first stage is a *validation* phase where the parameters of the model are adjusted to the set of producers under consideration until the model becomes able to reproduce "the observed surface allocations" (referred to also as observed solution or observed behavior in the text) for current prices and yields. The second stage is a *simulation* phase where the future situation is explored for different scenarios of policy measures and future prices.

The model implemented here contains in total 680 farms from two representative arable cropping regions of France (cereal and sugar-beet specialized region, FADN OTEX 13). The results of the first stage showed that in most of the cases the model could not satisfactorily reproduce the observed behavior of the farmers. This is possibly due to the combined effects of the uncertainty about crop prices and yields, two major components of the unit profits which are supposed to guide the choices of farmers. The aim of the present work is to investigate if the representative power of LP concerning farmers' behavior can be improved by taking into account price and yield variations. To model this uncertainty, intervals on gross margins per surface unit were introduced into the objective function of the model[23].

The Data and LP model validation

Arable crop farms considered belong to cereal oriented farms producing also rape-seed. Farm Accounting Data Network (FADN) data (orientations OTEX 13) on number of farms per type, surfaces cultivated, and land

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[23] This is a problem of decision making under risk. There is a rich literature on this subject that constitutes a subject matter of decision making on its own. A review of these methods can be found in [9] and in [8]. One could mention the E-V model non-linear or quadratic as well as its linearised versions such as MOTAD and target-MOTAD but also models based on game theory reasoning such as maximin, minmax, safety-first etc. models. For all these models, availability of covariance matrices – that require gross margins of individual crops related to different states of nature or years- are fundamental for efficient diversification among farm activities as a means of hedging against risk [15]. Consequently it is extremely difficult to apply these methods to regional models containing hundreds of farms precisely because of the requirement of detailed data at the farm level indicating those covariance relationships. Non-interactive methodologies that attempted to assess multi-criteria utility functions [1] are including at least one risk criterion thus always requiring detailed information at the farm level. As experimental applications of this method state [7] the risk criterion ranks second after the gross margin maximisation one in the multi-objective function having weights around 30%. This is probably the reason that all of the above method modelling implementation contain at best a few dozen of farms. As our intention is rather to represent diversity using big samples we opted for the interval LP whom only requirement is a good idea of the range of variation of gross margins. These ranges may be assessed at the regional level by crop using FADN or Agricultural Chambers census of big samples and they apply to all farms.

set aside concerning the above farm types have been used in this exercise along with detailed data on inputs of arable crops used by each farm [29]. The year 1996 has been chosen as the basis because the percentage of land set aside then fixed by the C.A.P. at 10% of the surface of cereals and oil and protein seeds, equals the one fixed by the Berlin agreement for the period 2000-2002. The horizon 2002 is taken as reference for the reason that CAP reform of 1999, will then be totally applied, after two years of transition 2000-2001. Arable farms have been selected out of a sample of 216 located in the cereal production oriented region of the North-East Ile-de-France). Profiles of the group are shown in Table 8. These farms represent adequately the diversity of arable cropping farms in the Central and Northern France.

Table8. Crop mix by region (results of the agricultural sector model)

in ha	cereal farm region	
	Average hectareage	profile
Arable land	7816744	%
Wheat	906415	0.12
Wheat mono-culture	3282808	0.42
Barley	545804	0.07
Winter barley	2071253	0.26
Corn	288961	0.04
Rape-seed	447984	0.06
Sunflower	4121	0.00
Wheat ethanol	-	-
Rapeseed-ester.	-	-
Set aside land	269398	0.03

In total, 216 elementary models were considered. Each individual farm model had up to 8 variables. The three variables representing set aside, set aside for rape-seed and set aside for wheat were common to all the models. These crops are cultivated through contracts signed with the ethanol and ester industry, their part in the total arable land is a result of tax exemptions on biofuels gratified by the government.

Regarding flexibility constraints right hand side limits can be reconsidered if necessary and after some iterations they can be adjusted always respecting statistical trends so that the model result approach the most possible reality (Table 9).

Table 9. Statistics for agronomic limits used as RHS in the flexibility constraints.

Agronomic limit for cereals in % of arable land	100%
Agronomic limit for oilseed crops in % of arable land	50%
Agronomic limit for rape-seed in % of arable land	30%
Agronomic limit for sunflower in % of arable land	20%
Agronomic limit for corn in % of historical surface	110%
Agronomic limit for peas in % of historical surface	110%
Agronomic limit for barley in % of historical surface	110%

Figure 3 presents the aggregated observed solution for the considered region and the LP results (i.e., the sum of optimal allocations by farm for each crop) at the end of the calibration procedure. The surfaces are expressed in hectares. As one can see, there exists some gaps between the observed and the optimized allocations for various crops: rape-seed for food and energy as well as sunflower are underestimated. The difference in absolute value between the observed production levels and the optimized allocations (in other words, the distance between the two solutions using a L_1 metric) is approximately 2.8 million ha. The total arable land considered being 7.8 million ha, the relative distance (the difference between the two solutions in absolute value divided by the total arable land) is 39%. However, at the microscopic or farm level (i.e. regarding the results of individual elementary models), the distances become more important: the relative average distance can be more than 66%. At the microscopic level, these results could be expected given the penny-switching nature of the LP, whereas at the sectoral level compensatory effects counteract in the aggregates making the model results to approach the observed crop mix.

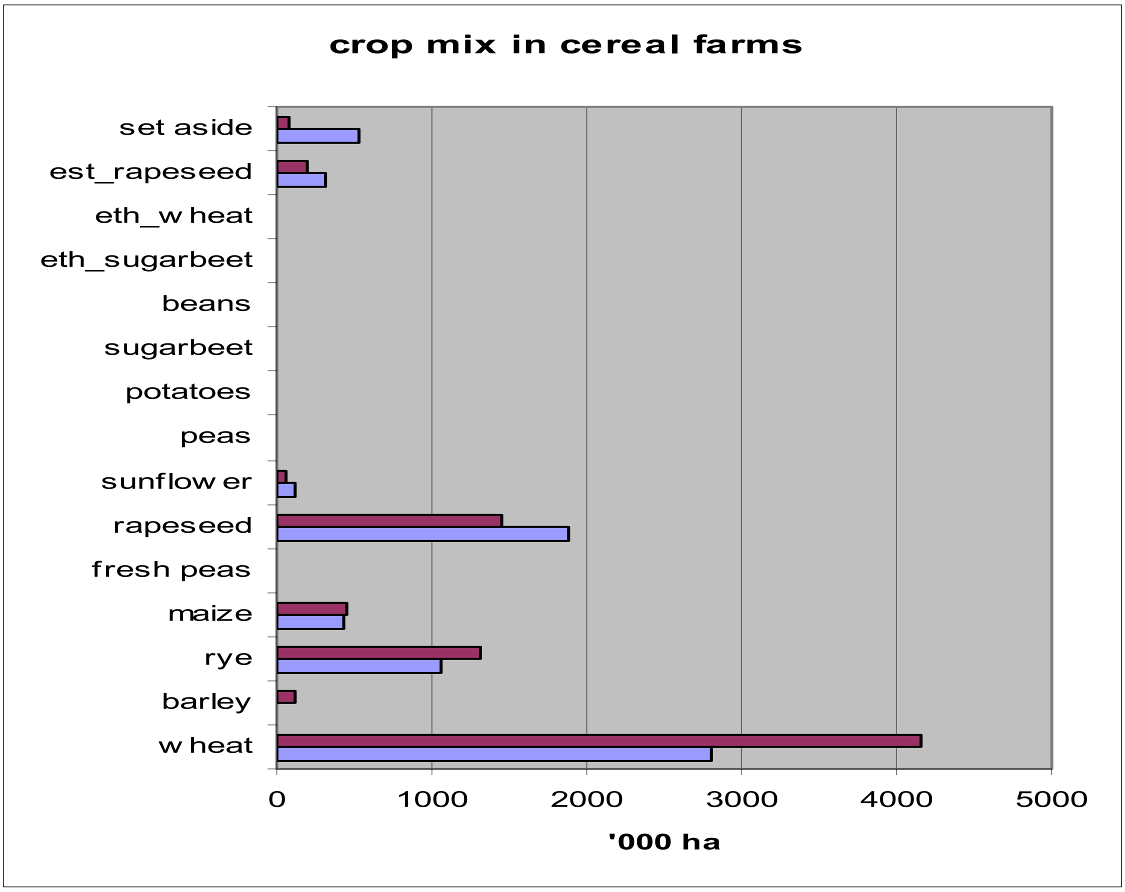

Figure 3. Comparison of the observed crop mix and the LP solutions at the regional level.

Hence, the need for improvement in the representativity of the model is clear. In all evidence, such distances can occur for two reasons: an inaccurate specification of the feasible regions of the models (which would be closely related to the calibration procedure) or an inaccurate specification of the objective functions. Considering the recent changes in the economic environment and the natural uncertainty of yields, we opted for investigating the problems that may arise because of a possibly inaccurate specification of the objective functions[24]. More precisely, we modified the original LP model to take into account uncertainty about prices and yields by using interval valued coefficients for the objective function. In the following paragraph, a brief review of the literature devoted to the subject and a formal definition of the Interval Linear Programming (ILP) problem will be given. Finally, two kinds of approaches concerning possible solution procedures will be outlined.The presentation of the formal interval linear programming problem is given in the next section.

3.1 ILP Models and related work

In mathematical programming models, the coefficient values are often considered known and fixed in a deterministic way. However, in practical situations, these values are frequently unknown or difficult to determine precisely. Interval Programming (IP) has been proposed as a means of avoiding the resulting modeling difficulties, by proceeding only with simple information on the variation range of the coefficients. Since decisions based on models that ignore variability in objective function coefficients can have devastating consequences, models that can deliver plans that will perform well regardless of future outcomes are appealing. More precisely, an ILP model consists of using parameters whose values can vary within some interval, instead of parameters with fixed values, as is the case in conventional mathematical programming.

Many techniques have been proposed to solve the resulting problem. Shaocheng [10] studied the case where all the model parameters are represented by intervals and the decision variables are non negative. Recently, Chinneck and Ramadan [4] generalized their approach to the case where variables are without sign restriction. The case which is of greater interest for our purpose is the one where only the objective function coefficients are represented by intervals. This particular problem is the most frequently considered in ILP literature (see, e.g., [2], [10], [11], [16], [17], [18], [22], [32]). We now introduce some definitions and notations and briefly present the formal problem.

Interval Linear Programming (ILP) Problem

Let us consider a Linear Programming (LP) model with n (real and positive) variables and m constraints. The objective function is to be maximized. Formally:

$$\max \{\mathbf{cx} : \mathrm{c} \in \Gamma, \mathbf{x} \in \mathrm{S}\} \qquad \text{(ILP)}$$

where

$$\Gamma = \{c \in \Re^n : c_i \in [l_i, u_i], \forall i = 1..n\}$$

$$S = \{x \in \Re^n : Ax \leq b, x \geq 0, A \in \Re^{m \times n}, b \in \Re^m\}$$

The uppercase letters with bold characters denote matrices (e.g., **A**). The lowercase letters with bold characters denote vectors (e.g., $c \in \Re^n, x \in \Re^n$). The null vector is denoted by 0. $[l_i, u_i]$ represents a closed interval of real numbers where l_i stands for the lower bound and u_i stands for the upper bound. The letters with indices indicate

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[24] Therefore, an implicit hypothesis is that the feasible region of each elementary model represents adequately the allocation possibilities of the farmers. Let us note that the observed solutions for each farm have been verified to be feasible in the corresponding model.

the elements of a matrix (e.g., $A = (a_{ij})_{m,n} \in \Re^{m\times n}$) or a vector (e.g., $c = (c_1,..., c_i,..., c_n) \in \Re^n$) or an interval (e.g., $l_i \in [l_i, u_i]$).

Let $\Pi = \{x \in S : x = \arg\max\{cy : y \in S, c \in \Gamma\}\}$ be the set of potentially optimal solutions. Let Y be the set of all the extreme objective functions: $\Upsilon = \{c \in \Gamma : c_i \in [l_i, u_i], \forall i = 1..n\}$.To give insight into what the problem becomes when intervals are introduced, we recall the following theorem [10], [32] :

Theorem 1

Let us consider the following multiobjective linear programming problem:

$\upsilon\text{-}max\{\mathbf{cx} : \mathbf{x} \in S;\ c \in Y\}$ *(MOLP)*

where the υ-max notation stands for the vector maximization. Then, a solution is a potentially optimal solution to (ILP) problem if, and only if, it is weakly efficient to the (MOLP) problem.

Hence, (ILP) is a particular multi-objective linear programming problem where the 2^n objectives are elements of Y and the set of potentially optimal solutions Π is the set of weakly efficient solutions to (MOLP). Theoretically, this knowledge enables us to mobilize all the tools and concepts of multi-objective linear programming literature, especially to choose/propose suitable solution concepts for (ILP) problem. In the literature, two distinct attitudes can be observed. The first attitude consists of finding all potentially optimal solutions that the model can return in order to examine the possible evolutions of the system that the model is representing. The methods proposed by Steuer [32] and Bitran [2] follow this kind of logic. The second attitude consists of adopting a specific criterion (such as the Hurwicz's criterion, the maxmin gain of Falk, the minmax regret of Savage, etc.) to select a solution among the potentially optimal solutions. Rommelfanger et al. [22], Ishibuchi and Tanaka [11], Inuiguchi and Sakawa [10] and Mausser and Laguna [16], [17], [18] proposed different methods with this second perspective. Following this perspective, the next section introduces the approach that we have selected, namely the minimization of the maximum regret approach, and the procedure we adopted for its implementation.

Minimizing the Maximum Regret

Minimizing the maximum regret consists of finding a solution which will give the decision maker a satisfaction level as close as possible to the optimal situation (which can only be known as a *posteriori*), whatever situation occurs in the future. The farmers are faced with a highly unstable economic situation and know that their decisions will be based on uncertain gains. It seems reasonable to suppose that they will decide on their surface allocations *prudently* in order to go through this time of economic instability with minimum loss, while trying to obtain a satisfying profit level. This is precisely the logic underlying the minmax regret criterion; i.e. selection of a *robust* solution that will give a high satisfaction level whatever happens in the future and that will not cause regret. Therefore, we make the hypothesis that the farmers of the considered region adopt the min-max regret criterion to make their surface allocation decisions. The mathematical translation of this hypothesis for the MAORIE was to implement the minmax regret solution procedure proposed in the literature (see e.g., [10], [16],

[17], [18]). The presentation of the formal problem and the algorithm of minmax regret are presented in the next paragraphs.

3.2 The MinMax Regret (MMR) Problem

Suppose that a solution $x \in S$ is selected for a given $c \in \Gamma$. The regret is then:

$$R(c,x) = \max_{y \in S}\{cy\} - cx$$

The maximum regret is:

$$\max_{c \in \Gamma}\{R(c,x)\}$$

The *minmax* regret solution $\hat{x}$ is then such that $R_{\max}(\hat{x}) \leq R_{\max}(x)$ for all $x \in S$. The corresponding problem to be solved is:

$$\min_{x \in S}\{\max_{c \in \Gamma}\{\max_{y \in S}\{cy\} - cx\}\} \qquad \textbf{(MMR)}$$

The MinMax Regret Algorithm

The main difficulty in solving (*MMR*) lies in to the infinity of objective functions to be considered. Shimizu and Aiyoshi [25] proposed a relaxation procedure to handle this problem. Instead of considering all possible objective functions, they consider only a limited number among them and solve a relaxed problem (hereafter called (*MMR'*)) to obtain a candidate regret solution. A second problem (called hereafter (*CMR*)) is then solved to test the global optimality of the generated solution. If the solution is globally optimal, the algorithm terminates. Otherwise, (*CMR*) generates a constraint which is then integrated into the constraint system of (*MMR'*) to solve it again for a new candidate solution. This process continues in this manner until a globally optimal solution is obtained. The relaxed (*MMR'*) problem is:

$$\min_{x \in S}\{\max_{c \in \Gamma}\{\max_{y \in S}\{cy\} - cx\}\} \qquad (MMR')$$

where $C = \{c^1, c^2, ..., c^p\} \subset \Gamma$. This problem is equivalent to:

$\min r$ (*MMR'*)

s.t. $r + c^k x \geq c^k x_{c^k}$, $k = 1, \ldots, p$

$r \geq 0,\ x \in S,\ c^k \in C$

where x_{c^k} is the optimal solution of $\max_{y \in S, c^k \in C}(c^k y)$. A constraint of type $r + c^k x \geq c^k x_{c^k}$ is called a regret cut. Let us denote $\bar{x}$ the optimal solution of (*MMR'*) and $\bar{r}$ the corresponding regret. Since all possible objective functions are not considered in (*MMR'*) we cannot be sure that there is no *c* belonging to $\Gamma \setminus C$ which can cause a greater regret by its realization in the future. Hence, we use the following (CMR) problem to test the global optimality of $\bar{x}$:

$$\max_{c\in\Gamma}\left\{\max_{y\in S}\{cy\}-c\bar{x}\right\} \qquad \textit{(CMR)}$$

Observe that the objective function value of (CMR) represents the maximum regret for $\bar{x}$ over Γ, denoted by $R_{\max}(\bar{x})$. If the optimal solution $x_{c^{p+1}} \in S, c^{p+1} \in \Gamma$ of (CMR) gives $R_{\max}(\bar{x}) > \bar{r}$, it means that c^{p+1} can cause a greater regret than $\bar{r}$ by its realization in the future and that it has to be considered also in C while solving (*MMR'*). So, the regret cut $r + c^{p+1}x \geq c^{p+1}x_{c^{p+1}}$ is added to the previous constraint set of the (*MMR')* to solve it again and obtain a new candidate. The process is iterated until the generated candidate regret solution is found to be optimal by (CMR). This solution procedure idea is summarized with the following algorithm:

MinMax Regret Algorithm

```
Step 0:  $r^\circ \leftarrow 0, k \leftarrow 0,$ choose an initial candidate $\bar{x}$
Step 1:  $k \leftarrow k+1,$ Solve (CMR) to find $c^k$ and $R_{\max}(\bar{x})$ :
         If $R_{\max}(\bar{x}) = r^\circ$ then END. $\bar{x}$ minimize the maximum regret.
Step 2:  Add the regret cut $r + c^k x \geq c^k x_{c^k}$ to the constraint set of (MMR')
Step 3:  Solve (MMR') to obtain a new candidate $\bar{x}$ and $\bar{r}$ . $r^\circ \leftarrow \bar{r}$ . Go to Step 1.
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The difficulty in this resolution process lies in the quadratic nature of the (CMR) problem. Inuiguchi and Sakawa [10] investigated the properties of the minmax regret solution to find a more suitable way to solve (CRM). Mausser and Laguna [16] used their results to formulate a mixed integer linear program equivalent to (CMR) which is less costly to solve. In our experiments we used this equivalent problem formulation (Appendix A).

4. Implementation of the MMR Approach

In a relatively stable environment, it is reasonable to suppose that farmers will base their decisions on average prices. MAORIE is originally designed under this very assumption: objective function coefficients (the gross margins per crop) are calculated based on the 1993-1997 price and yield averages. As a matter of fact, in the present context, the natural uncertainty about yields is combined with an increasing uncertainty about prices. Therefore, the farmers would tend to consider ranges of gross margin instead of average prices and yields to make their decisions. For this reason, the objective function coefficients, which correspond to unit gross margins per crop, will be represented by intervals in the modeling.

The figure 4 shows variability of rapeseed sales (right side graph) observed in 650 farms of the Centre-Northern France due to yield and price variations. Total uncertainty can be represented by the range determined by $\mu\pm2\sigma$, where μ is the mean value and σ the standard deviation of the sales distribution. Table 10 summarizes intervals of gross margins for different crops.

Table 10. Average and standard deviation of sales value for selected crops

	average sales	stdev sales	(av+2std)/av	±%margin*
winter wheat	873.87	118.35	0.27	±33
Rapeseed-sunflower	622.22	131.33	0.42	±63
winter barley	782.10	122.39	0.31	±39
barley spring	831.20	119.61	0.29	±32
maize grain	843.10	159.18	0.38	±52
peas	598.77	157.90	0.53	na**
sugarbeet	2992.61	433.96	0.29	na

**variation in sales value results in higher percentage variation in gross margin*

*** not applicable in the cereal region*

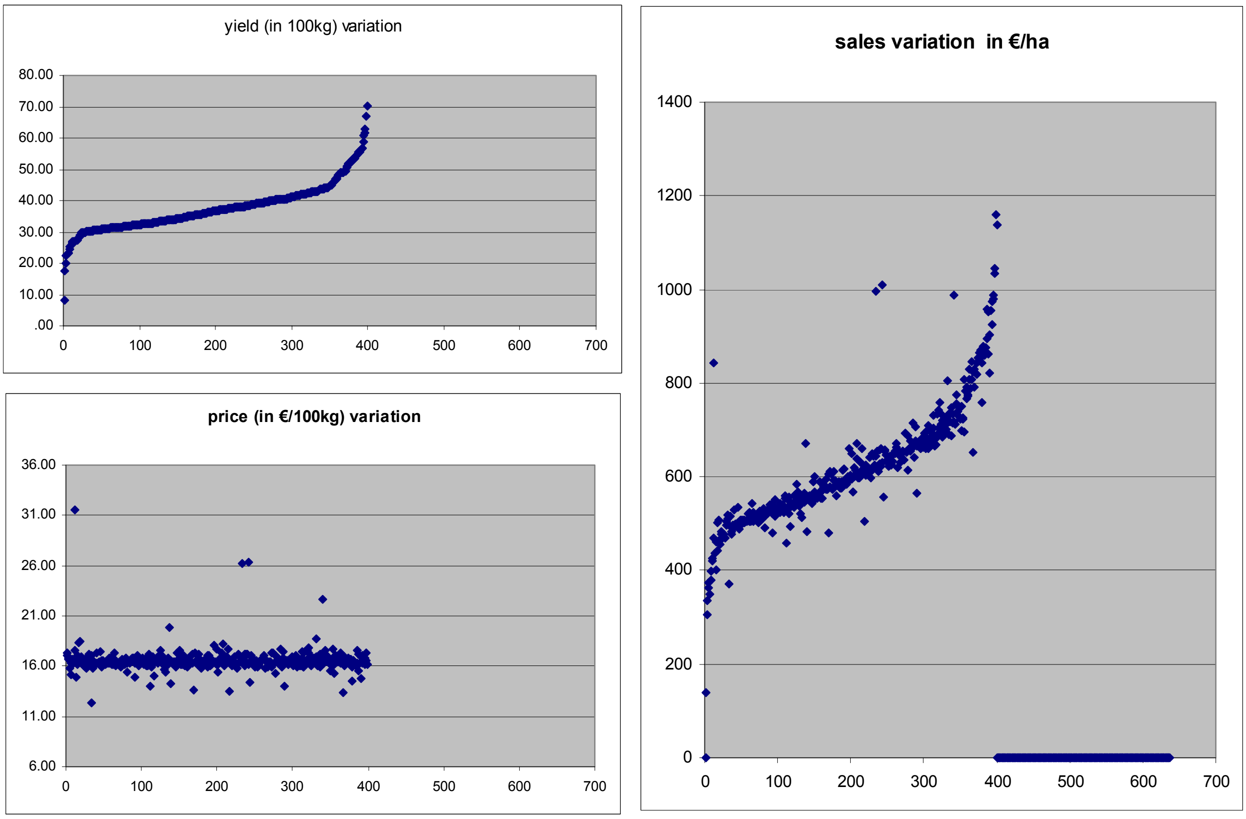

Figure 4. Cumulative distributions of yield, price to the farmer and total sales value of rapeseed

Gross margin intervals have been used in the model for 6 crops, namely wheat, rapeseed and sunflower, winter and spring barley, and grain corn, calculated according to the table 4 data. Energy crops present lower but stable prices compared to their food counterparts. Moreover, they are cultivated under 8-year contracts so we did not use interval coefficients for them and kept the original parameters (gross margins). Hence, for our (ILP) models, the number *s* of interval-valued coefficients is fixed at 6.

The interval linear programming approach with the minmax regret criterion applied to the MAORIE model objective function has been implemented to investigate if its representativity can be improved by this approach[25]. For the initial regret candidates to start the algorithm, we used the optimal solutions of MAORIE. Comparison of the minmax regret approach distances versus the ones obtained by the LP results in about 70 % of the farms following minmax regret criterion vs. profit maximization function.

4.1 Analysis of the Results

Despite the battery of explicit (rotation) and implicit (flexibility) constraints of MAORIE[26] the penny-switching nature of conventional LP prevails in many cases. We indicate some cases in order to better understand the utility of the MMR approach:

Observation 1 Since the gross margin of irrigated peas is in all cases inferior to irrigated corn, MAORIE allocates all the irrigable surfaces to this second crop, although the production of the first one has been observed in about 20 farms.

Observation 2 For the cases where the gross margin of wheat is inferior to the gross margins of rape-seed and sunflower, no surface was allocated by MAORIE to the wheat although its production was observed in every case.

The principal effect of the ILP approach with the MinMax Regret is:

Observation 3 For the two previous cases, when the differences between the gross margins is relatively small, the minmax regret approach gives more "balanced" solutions, and this more so when the interval coefficients get larger (i.e., when j increases).

This last observation seems reasonable. In fact, as the intervals get larger, the interval gains for different crops start to overlap or, if they already have an intersection, they become more overlapping. It becomes more difficult to anticipate which crop will be more profitable. Hence, the minmax regret approach tends to return more and more balanced solutions as the size of the intervals increase. A detailed discussion on this point is presented by Kazakci and Vanderpooten [13].

The effects of the minmax regret approach on the proximities obtained at the microscopic level are considerable: for about 55% of the farms, the relative distance (M_1^j) of the minmax regret solution to the corresponding observed solution is smaller than the relative distance[27] of the LP's optimum solution to the observed one. when

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[25] GAMS software is used to implement the proposed minmax regret algorithm and the linear and integer programming modules of the CPLEX solver. The model is available from the authors upon request.

[26] MAORIE: the French sector LP model (Modèle Agricole d'Offre Régionale INRA Economie)

[27] To evaluate the proximity of the j^{th} minmax regret solution x_k^j to the observed solution x_k^{obs} for the farm k, we used the following performance measure:

$$M_1^j\left(x^j\right) = \frac{L_1\left(x^j, x^{obs}\right)}{TotalLand} = \frac{\sum_i \left|x_i^j - x_i^{obs}\right|}{\sum_i x_i^{obs}}$$

the model is solved, the returned solution is compared to the observed solution to see the *distance*. Concerning the improvement in the proximities to the observed solutions, the worst proximities ($\max\left(M_1^j\right)$) obtained for these 55% of the farms provide an average improvement of 11% with respect to MAORIE's proximities (denoted by $M_1^j\ (x^{opt})$ in the figures, where x^{opt} stands for the MAORIE's optimal solutions for the corresponding farms). From these observations, we may conclude:

Conclusion 1 In the cases where the farmers choose a balanced allocation, the min-max regret solutions tend to improve the representativity of the model

Conclusion 2 More than half of the farmers' decisions are not based on the maximization of the profit logic underlying the LP model.

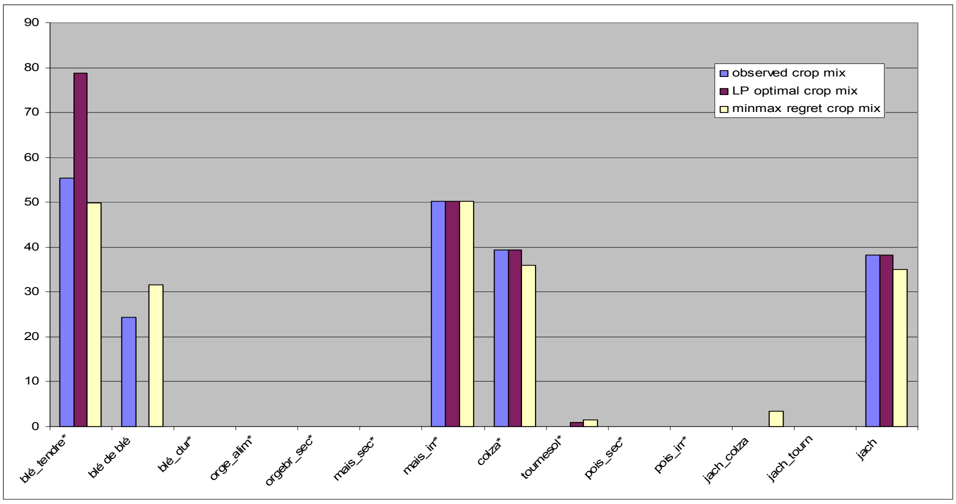


Figure 5. Comparison of the minmax regret Solutions with the Observed and the Optimal LP Solutions at the farm level (surfaces in ha).

For each individual farm elementary model a simple algorithm replaces the objective function with that, between gross margin maximization and minmax regret, performing better in terms of proximity of the resulted crop mix to the observed one. This way we end up with a *hybrid* model with two possibilities of objective function. This model has by definition a higher predictive capacity than the initial LP, so it will be used to generate energy crops supply curves in order to feed the multi-level biofuel system national model.

Opportunity costs aggregation to supply curves of energy crops may give paradoxical results at the farm level (see fig. 6) but it always results in aggregate supply curves consistent to the theory when a sufficiently large number of elementary producers are involved (fig. 7). To paraphrase Simon (26): "..empirical data do confirm that supply curves generally have positive slopes.. but positively sloped supply curves could result from a wide range of behaviours satisfying the assumptions of bounded rationality rather than those of utility maximisation".

Two factors affect the relative position to the supply curve generated by the LP, first the fact that the objective function value in terms of total farm gross margin at the minmax regret optimum is lower than the LP optimal value (results in lower opportunity cost), but also that the energy crop giving stable gross margin is appreciated in the farm comparing with other crops with considerable variability (higher opportunity cost).

Depending on the above factors as well as the interaction with the constraint structure the minmax supply curves is located to the right of the LP curve but up to a certain quantity level. Quantities used in the biofuel industry float in this range, thus we consider that the minmax criterion adoption results in lower opportunity costs of biomass raw material for the biofuel industry.

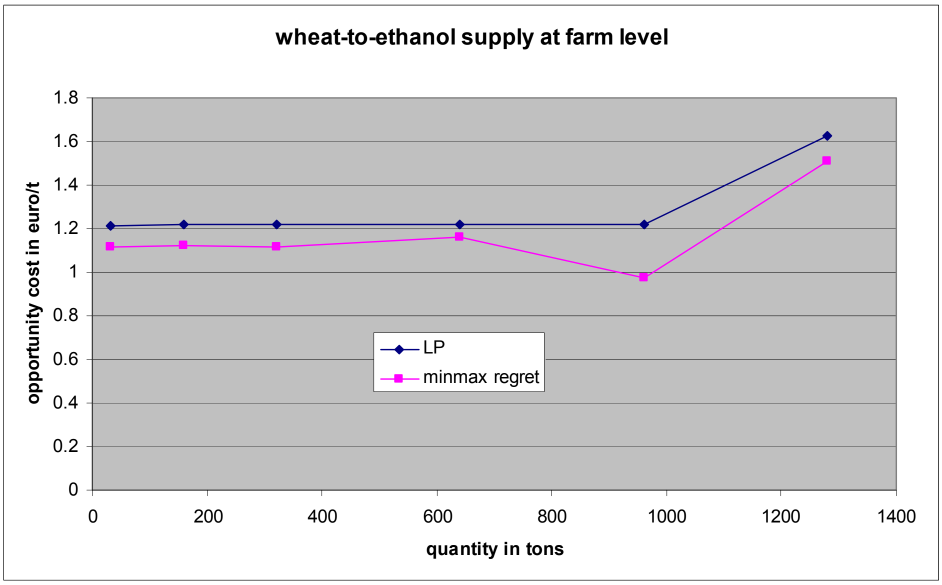


Figure 6. Supply curves resulted by max profit and min-max regret objectives at the farm level

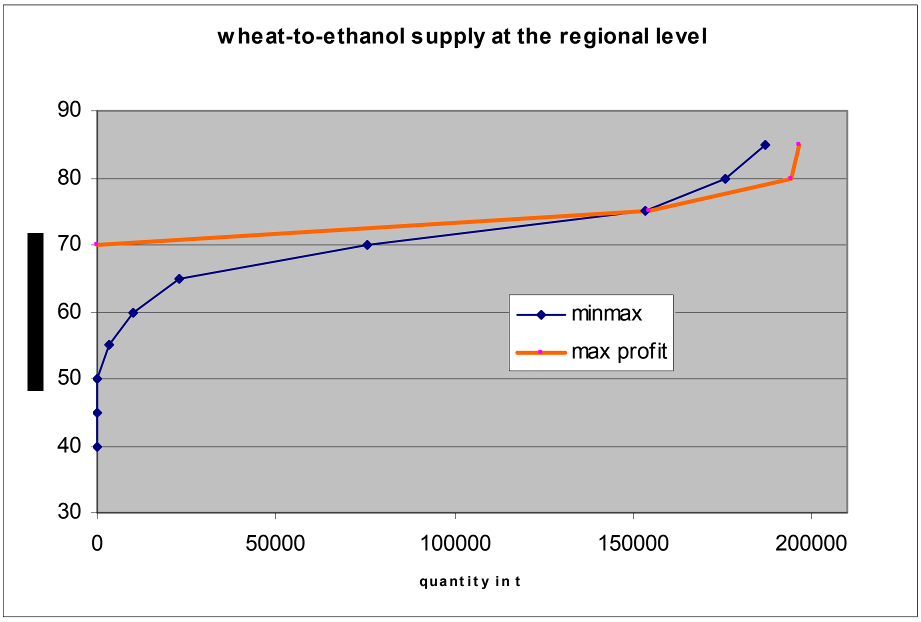


Figure 7. Supply curves resulted by max profit and min-max regret objectives at the regional level

5. Public decision-making in a controversial environment

A first reaction of the public DM, who attempts to practice efficient public policy, would be to focus on tax exemption schemes resulting in minimal total expenditure. Alternatively, it could seem reasonable to select alternatives that tend to exhaust available funding. This implies that, in reality, other policy objectives exist behind the pursuit of a single objective such as budgetary discipline. Government opts for other priorities beside budgetary concerns such as supporting farmers' income and, last but not least, reducing greenhouse gas emissions (GHG). In the following paragraphs, objectives relevant to bio-fuel activity are going to be defined and a multiple criteria decision making process is proposed in order to search for a compromise solution.

Concerning environmental effects, this analysis focuses on GHG and particularly carbon dioxide emissions. Bio-fuel use can reduce fossil fuel consumption and increase carbon storage in plants. When bio-fuels are burned the CO_2, absorbed by the growing plant during photosynthesis, is re-emitted. Therefore, on a global basis, no net CO_2 emissions would occur, if biomass production was maintained to replace material that is burnt and no fossil fuels were used in the production and conversion processes. In practice though, fossil fuels are used in the bio-fuel production process (fertiliser manufacturing, farm machinery operation, energy during conversion of crops to bio-fuels). The overall effect on net CO_2 emissions then depends on the balance between this fossil fuel use and the fossil fuels displaced by the bio-fuels. Studies attempting to estimate environmental externalities from bio-fuel production in France have been based on Life Cycle Analysis (LCA)-estimates by OECD/IEA published in 1993 and 1994 [9]. Figures used to build the criterion *CO_{2eq} savings* are based on estimates reported for ester and ethanol respectively [10-12], as shown in table 3.

Regarding effects on farmers' incomes, the *agricultural surplus* provided directly by the agricultural sector model can be used as a proxy for government's objective to improve farmers' welfare. The agricultural surplus is the producer surplus that corresponds to the difference between the values of the agricultural sector model objective function with and without energy crops (equation 1 in the Annex I).

Global surplus is the net economic effect of the activity and is calculated as the difference between gains (industry profits and agricultural surplus) and subsidies. As bio-fuel industry depends on subsidies, its global surplus is negative (usually called 'deadweight loss' in welfare economics terms). An increase of the activity may result in higher profits but, in any case, an overall loss in terms of global surplus will be incurred. Thus, profits and global surplus are in conflict.

The graph in Figure 8 helps to visualise values that alternative solutions take with regard to the two most important (and conflicting) objectives, namely government expenditure (to be minimised, x-axis) and CO_{2eq} emission reductions (to be maximised, y-axis). The efficient frontier contains 9 non-dominated points among 475 alternative solutions.

This graph would be sufficient to support the decision process if only two criteria were considered. However we argued that more criteria should be used if we wished to represent each stake-holder's viewpoint. For this reason we selected the following criteria: agricultural surplus, surplus of ester chain, surplus of ethanol chain, earmarked budget, GHG savings. In the 5-dimension decision space, the number of efficient solutions increases to 226. Thus, the exploration of the universe of efficient solutions and of all possible trade-offs among criteria becomes a rather complex task. For this purpose an interactive multi-criteria method based on a reference point approach has been implemented (see in Annex D, and [36]). Aspiration levels, set by the DM expressed on the criteria units, are projected onto the efficient frontier resulting in a solution corresponding to a specific tax exemption scheme (solution closest to the targets). The exploration is supported through an interactive adjustment of the aspiration levels on the basis of solutions generated at previous iterations. This approach has been used in various contexts, in particular in contexts involving environmental aspects [20, 31].

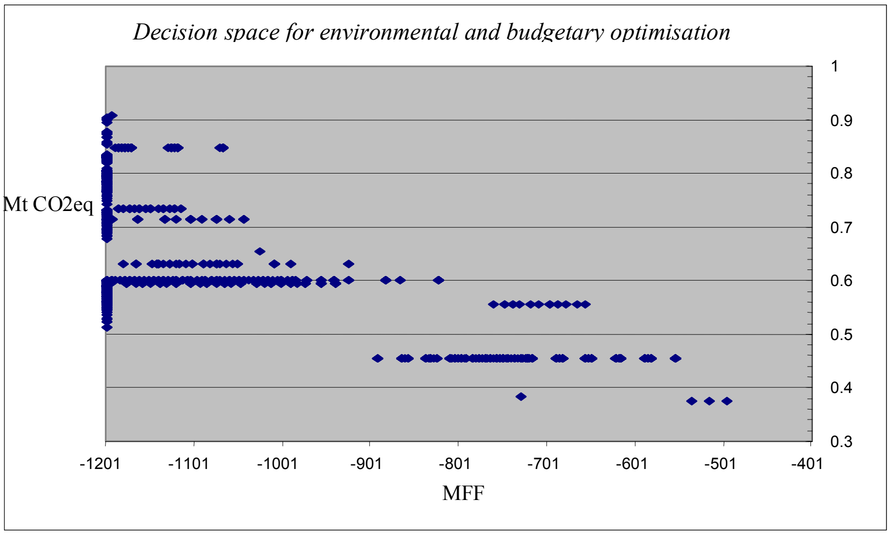


Figure 8. Alternative solutions in a bi-criteria space
Public expenditure in negative values (to minimise) versus GHG abatement (to maximise) :
ideal point (-497 MFF, 0.909 Mt CO_{2eq}) at the north-east corner.

The initial information of the multi-objective problem can be obtained by the optimisation of each of the objectives over the efficient set and the computation of the value of all other objectives at each of the optimal solutions. The pay-off matrix provides all this information (Table 12-Appendix D), that illustrates conflicts among strategies as well as possible trade-offs and in a synthetic way. Results of the maximisation of agricultural surplus are shown in the first row of the Table 11 (and also in the following four rows as there are multiple optima in this case). The second element of the first row means that for the maximum agricultural surplus optimal solution corresponds to a surplus of 194.33 MFF for the RME chain and 27.13MFF for the ethanol one, whereas budget amounts at 1192.98 MFF and total GHG emissions avoided are estimated at about 900 000 t equivalent CO_2. In addition, pay-off matrix provides ideal point and nadir point co-ordinates for each criterion. These values indicate ranges of variation for each criterion where efficient solutions are located. Notice that similar solutions optimise both agricultural surplus and CO_2 savings (one of the solutions optimising agricultural surplus is actually the one optimising CO_2 savings). In this case, interests of farmers and environmentalists coincide as the more biomass is produced for energy the less GHG quantities are emitted to the atmosphere.

The decision making process can be reserved to public policy makers or, alternatively, include stakeholders. During the interactive process, decision makers specify aspiration levels to be achieved. Also, worst levels acceptable (reservation levels) may be set for one or more criteria restricting the set of alternatives included in the decision space. Aspiration and reservation levels should be set within efficient ranges of variation. After some iterations, possibilities of compromise and corresponding trade-offs can be explored. In order to initiate the exploratory process, one can start by projecting the ideal point onto the efficient frontier

In case of aiming at the ideal point, the alternative of 2 ester and 1 ethanol transformation units, is selected, corresponding to the unitary tax credit vector {subEth:3.30 FF l^{-1}, subEst:2.50 FF l^{-1}}. This solution seems interesting but it could be improved especially regarding public spending. So, aspiration levels are set at this solution point except for public spending which is attempted to reach its optimum (column 2 in Table 13-Appendix D).

Projection results in lower expenditures (unitary tax credits of subEth: 3.00 FF l^{-1}, subEst:2.00 FF l^{-1}), reducing considerably industry profits. In terms of trade-off between public expenditure and CO_2 savings, this efficient solution suggests that the DM accepts a lower level of 100 thousand t of CO_2 savings for a budgetary gain of 369 MF. When environmental concerns prevail one can set temporarily a reservation level on criterion 'CO_2 savings'(three last columns in Table 13-Appendix D). In this case, the set of alternatives decreases to 75 candidate solutions, and unitary tax credits vary around 2.30 FF l^{-1} for both ester and ethanol chains increasing also the total amount of expenditure as 2 transformation units for both chains are proposed. By revising aspiration and reservation levels in successive rounds DM can thus freely but systematically explore the set of efficient solutions.

6. Conclusions

OSCAR is a partial equilibrium model that allows for micro-economic analysis of the bio-fuel industry by applying an integrated (chain oriented) and systemic (multi-chain optimisation) approach. It is proved capable of evaluating alternative policy schemes satisfactorily, moreover, suitable to support multi-criteria analysis. The data used in this model are fairly detailed, especially in the agricultural sector, and allow for the parameterization of technical and economic coefficients. The agricultural component of the model has been enriched by interval programming taking into account the uncertainty that prevails in the arable agriculture thus enhancing the validity of modelling tools. LP model where maximisation of expected profit prevails as a distinctive feature of substantive rationality gives hardly valid results plotted against observed farmers' decisions. Comparing with the restrictive interpretation of rationality in absence of systematic ex-post mistakes, min-max regret behaviour has been selected in about 70 % of the cases performing better than classic profit maximizing behaviour against observed crop mix choices. Biomass-to-energy supply curves are consequently modified with respect to LP ones, reflecting appreciation of energy crop in a context where individuals take seriously into account the notion of 'regret', resulting in lower opportunity costs within the range of interest for biofuel industry.

The aim of this study was to estimate the micro-economic cost of bio-fuels resulting from the efficient use of resources, for the year 2004. This minimisation of biomass opportunity costs 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 transformation-to-energy activity 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 5) and by the positive externalities generated by the bio-fuel activity.

Calculations have determined oil price levels that make biofuels profitable (financial profitability) and those that make biofuels interesting from the society point of view (economic profitability) shown in Table 11. Backward linkages of the oil price change has been considered also. This effect is important as energy balances, while positive, contain significant inputs of fossil fuels, especially concerning ETBE. In order to assess the social cost of biofuels we take into account the following elements (additionally to the private cost assessment)

- farmers'surplus (value-added to the producers)
- decrease of European support (CAP) to sugarbeet
- positive externalities with regard to the greenhouse effect[28] (RME : 4.02 €/l, ethanol : 2.31€/l, ETBE : 1.02 €/l for emissions of carbon ton avoided valued at 76.22€ -originally 500 FF set by the French climate monitoring Commission)
- the impact to the economy caused by agricultural input demand increase comparing with set aside

Table 11. Oil threshold price levels in $ per barel by biofuel to break even

Biofuels	Private cost basis	Social cost basis
ETBE wheat	57	48
Ethanol wheat	46	36
ETBE sugarbeet	65	49
Ethanol sugarbeet	55	38
Rape-seed methyl ester (RME)	54	32

** regarding sugarbeet, CAP support decrease is considered, equals 0.023 €/l of ETBE, that is 0.052 €/l of ethanol.*

Furthermore, an interactive multi-criteria optimisation module supports the exploration of various tax exemption schemes focusing on all efficient alternatives provided by the micro-economic model. Criteria can be expressed in their proper units, which allows a decision process respecting incommensurability. Among various theories that formalise commonly understood human behaviour as based on a set of multiple and conflicting criteria, the so-called 'reference point' approach has been adopted here. It is assumed that the rationale of public choice in the controversial environment of energy policy is that alternatives that are closer to an ideal or target point are preferred to those that are further away. Efficient policy schemes are suggested through this process which cannot be intuitively determined. As a matter of fact, the reference point algorithm results in efficient alternatives as shown through illustrative examples of the decision making process, that improve policy performance with regard to environmental targets with no increase in public expenditure.

References

[1] Amador F., J.M.Sumpsi, C.Romero, *A non-interactive methodology to assess farmers' utility functions: An application to large farms in Andalusia*, European Review of Agricultural Economics 25 (1) 92-109

[2] Bitran G., *Linear multiple objective problems with interval coefficients*, Management Sciences **26** (1980), 694-705.

[3] Brooke A., Kendrick D., Meeraus A., Raman R., (1998) GAMS, A User's Guide, GAMS Development Co..

[4] Chinneck J. W. and K. Ramadan, *Linear programming with interval coefficients*, Journal of Operations Research Society **51** (2000), 209-220.

[5] Costa S., V. Requillart, *Evaluation publique de la production des bio-carburants¨Application au cas de l'ester méthylique de colza*, Economie et Prévision (2000), no 142, 2000-1

[6] EcoBilan. Guide pratique de realisation des ecobilans pour les industries agro-alimentaires. Ministère de l'Agriculture et de la Peche (1996).

[7] Gomez-Limon J.A., L.Riesgo, M.Arriaza, *Agricultural risk aversion revisited: A multicriteria decision-making approach*, paper presented in the Xth Congress of the EAAE, Zaragoza (2002).

[8] Hardaker J.B., Huirne R.B.M., Anderson J.R., Coping with Risk in Agriculture, CAB International (1997)

[9] Hazell P. and R.D. Norton, *Mathematical programming for economic analysis in agriculture*, Macmillan, h;m; New York (1986).

[10] Inuiguchi M. and M. Sakawa, *Minmax regret solutions to linear programming problems with an interval objective function*, European Journal of Operations Research **86** (1995), 526-536.

[11] Ishibuchi H. and H. Tanaka, *Multiobjective programming in the optimization of the interval objective function*, European Journal of Operations Research **48** (1990), 219-225.

[12] Kazakçi A.O., *Programmation linéaire par intervalles pour étudier l'offre agricole dans la région poitou-charentes, représentation de l'incertitude sous formes des intervalles dans la fonction objectif du modèle* MAORIE, Mémoire de DEA 35 (2001), INA-PG, Thiverval-Grignon, France.

[13] _____ , D. Vanderpooten (2002), Modelling the uncertainty about crop prices and yields using intervals: The min-max regret approach, in Rozakis & Sourie (eds.), *Options Méditerannéenes*, Special Issue *'Comprehensive modeling of bio-energy systems*', Serie A, n°48, pp. 9-22

[14] Loomes G., R. Sugden, *Regret theory: An alternative theory of rational choice under uncertainty*, Economic Journal, 92 (1982), 805-824

[15] Markowitz H.M., *Portfolio selection: efficient diversification of investments*, New York, Wiley (1959).

[16] Mausser H. E. and M. Laguna, *A new mixed integer formulation for the maximum regret problem*, International Transactions of Operations Research **5** (1998), 389-403.

[17] ____, *A heuristic to mini-max absolute regret for linear programs with interval objective function coefficients*, European Journal of Operations Research **117** (1999), 157-174.

[18] ____, *Minimizing the maximum relative regret for linear programmes with interval objective function coefficients*, Journal of the Operations Research Society **50** (1999), 1063-1070.

[19] Mavrotas G., S.Rozakis, A mixed 0-1 MOLP approach for the planning of biofuel production, in *Options Méditerannéenes*, S. Rozakis & J.C. Sourie (eds.), Special Issue *'Comprehensive modeling of bio-energy systems*', Series A - N° 48 (2002), CIHEAM.

[20] Perny P., Vanderpooten D. *An interactive multiobjective procedure for selecting medium-term countermeasures after nuclear accidents.* J. Multi-Crit. Decis. Analysis 1998. 7: 48-60

[21] Reinhardt G. A. First total ecological assessment of RME (Biodiesel) vs. diesel oil. In: Proceedings of the 10th European Biomass for Energy Conference, Wurzburg, Germany, 1998. p. 116-119.

[22] Rommelfanger H., *Linear programming with fuzzy objectives*, Fuzzy Sets and Systems **29** (1989), 31-48.

[23] Shaocheng T., *Interval number and fuzzy number linear programming*, Fuzzy Sets and Systems **66** (1994), 301-306.

[24] Scharmer K., Gosse G. Energy Balance, Ecological Impact and Economics of Bio-Diesel Production in Europe. ALTENER program 41030/E/94-002-01, GET/INRA (1996).

---

[28] DP hypothesis, Ministère des Finances, Levy-Couveihnes report :

[25] Shimizu K. and E. Aiyoshi, *Necessary conditions for min max problems and algorithms by a relaxation procedure*, IEEE Transactions on Automatic Control **25** (1980), 62-66.

[26] Simon H., *Rational decision making in business organisations*, American Economic Review (1979), v.69-4: 493-513

[27] Sourie J-C, JC Hautcolas, P Bonnafous, *Un bilan micro et macro-économique des biocarburants et les perspectives de réduction des coûts*, (1997), Actes du colloque AGRICE : 49-57

[28] ____, *Contributions aux travaux de la mission Biocarburants JD Levy, P Couveinhes,* unpublished document (2000), INRA ESR Grignon.

[29] ____, G. Millet, E. Kervegant, and P. Bonnafous, *Incidences de l'agenda 2000 sur l'offre de céréales, d'oléagineux et de protéagineux. applications du modèle* MAORIE, Etude Economique 38, INA-PG, Thiverval-Grignon, FRANCE, juin 2000, Série Etudes Economiques.

[30] ____, S. Rozakis, (2001) *Bio-fuel production system in France: An Economic Analysis*, Biomass and Bio-energy, Vol. 20-5: 483-489, May.

[31] Stam A., Kuula M., Cesar H. *Transboundary air pollution in Europe: An interactive multi-criteria trade-off analysis.* European Journal of Operational Research 1992. 56: 263-277.

[32] Steuer R., *Algorithms for linear programming problems with interval objective function coefficients*, Mathematics of Operations Research **6** (1981), 333-349.

[33] ____, Multiple Criteria Optimization. New York: Wiley, 1986.

[34] van den Bergh J.C.J.M., A. Ferrer-i-Carbonell, G. Munda, *Alternative models of individual behaviour and implications for environmental policy*, Ecological Economics 32 (2000), 43-61

[35] Vollebergh H., *Environmental externalities and Social Optimality in Biomass Markets*, Energy Policy 1997. 25(6): 605-621

[36] Wierzbicki A. *A mathematical basis for satisficing decision making,* Mathematical modelling 1982, 3:391-405.

[37] Williams H.P., Model Building in Mathematical Programming, (1985), John Wiley & Sons.

MIP version of quadratic MRC

The objective function of CMR (candidate regret solution testing model) is written as $R_{\max}\left(x^*\right)=\sum_i c_i\left(x_i-x_i^*\right)$; the c-consistency property implies that for each *i*, $c_i=l_i$ or u_i depending on the sign of the difference $\left(x_i-x_i^*\right)$. We define the non-negative variables y_i and z_i as follows:

$$x_i-x_i^*=z_i-y_i \qquad i=1,\dots,n \qquad (1)$$

If for each *i* only one among y_i and z_i takes a non-negative value, we will have the sign and the value of the difference $x_i-x_i^*$ that would give also the value of c_i; thus the objective function could be rewritten as $R_{\max}\left(x^*\right)=\sum_i\left(u_iz_i-l_iy_i\right)$. This function is no longer quadratic; in order to make sure that either y_i or z_i will be zero, although avoiding to add nonlinear-constraints ($y_iz_i=0$) we proceed by introducing binary variables and one auxiliary parameter denoting an upper bound; instead of $y_iz_i=0$ the following couple of constraints is used:

$$\begin{aligned}&y_i-x_i^*b_i\le 0\\&z_i-\left(B_i-x_i^*\right)\cdot\left(1-b_i\right)\le 0 \qquad i=1,\dots,n \qquad (2)\end{aligned}$$

when the binary variable *b* takes the value 1, z_i is obliged to take the value 0, whereas when *b* equals 1, y_i has to be equal to zero. Adding the constraints (1) in the model, we make sure that the differences $\left(x_i-x_i^*\right)$ are represented either by y_i or z_i, at the same time respecting natural constraints such as $z_i\le B_i-x_i^*$ or $y_i\le x_i^*$. The CMR model is formulated as below:

maximise

$$R_{\max}\left(x^*\right)=\sum_i\left(u_iz_i-l_iy_i\right)$$

subject to:

$$x_i-x_i^*=z_i-y_i \qquad i=1,\dots,n$$

$$y_i-x_i^*b_i\le 0 \qquad i=1,\dots,n$$

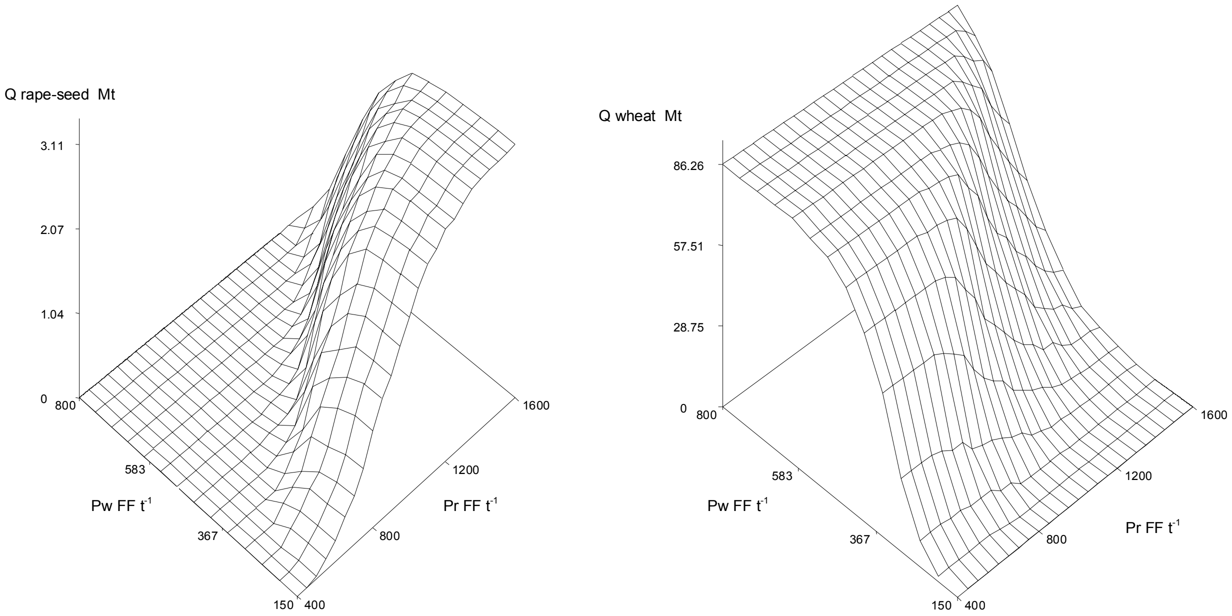
$$z_i-\left(B_i-x_i^*\right)\cdot\left(1-b_i\right)\le 0 \qquad i=1,\dots,n$$

$$\begin{aligned}&X\in S\\&y_i,z_i\ge 0 \qquad i=1,\dots,n\\&b_i\in\{0,1\}\end{aligned}$$

Appendix B

Outputs of the agricultural model are quantities of crops produced by the agricultural sector for predefined sets of prices offered by bio-fuel industry that equal marginal costs of energy crop production. In this case, two energy crops, namely wheat for ethanol and rape-seed for methyl esters, are used as representative energy crops. A grid of all possible prices at which energy crops can be sold at the farm gate is constructed (which define set *J*). Prices that fall outside this grid are either too low resulting in zero quantities being produced, or too high without any additional stimulating effect. Then, we perform successive iterations solving the model for all possible pairs of prices ($p_{\text{wheat}} = \{0.30, \ldots, 0.80\}$ and $p_{\text{rape-seed}} = \{0.60, \ldots, 1.60\}$ in FF kg^{-1}) in order to obtain corresponding optimal quantities produced as well as all relevant magnitudes (land cultivated for energy crops, set aside land, agricultural sector surplus). Note that these quantities are not determined independently; they take into account cross-price effects between energy crops (Fig. 9).

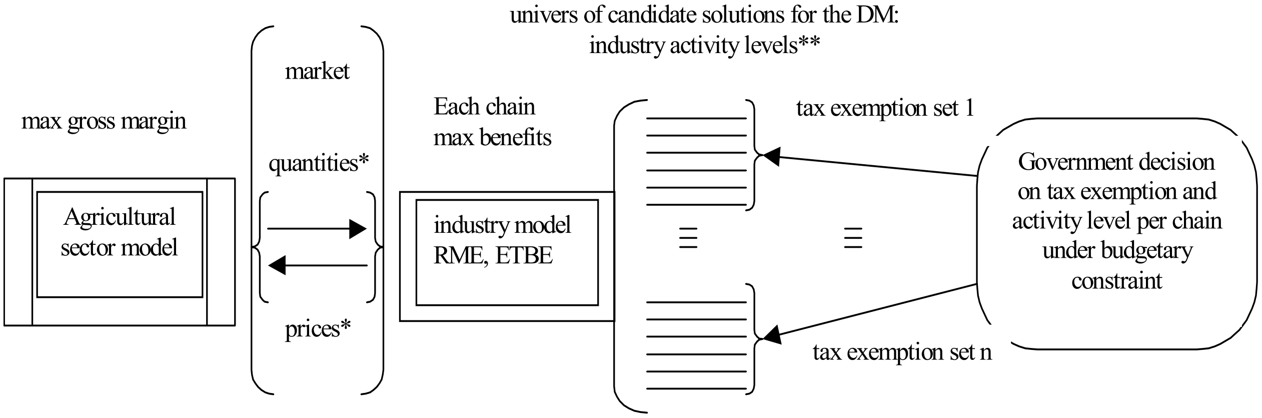
Figures 9. Supply surfaces of energy crops and cross-price effects



Generating discrete alternative configurations of bio-fuel activity

The micro-economic model represents the agro-energy chain mechanics and cost structure by simulating the farmers and industry behaviour. This allows the government to evaluate support policies for stimulating bio-fuel production. Industry is in the core of the chain. Taking into account its own cost structure (fixed vs variable costs, available capacities etc.), the level of tax credits (set by government) and material input cost (based on farmers response to energy crop prices), each industrial chain decides upon levels of activity (bio-fuel quantities to produce annually) in order to maximise its own profits. First, the agricultural sector regional model maximises total gross margin and determines quantities of crops offered to the market for different sets of crop prices. Then, the industry model considers supply curves of energy crops, and, given unitary tax exemptions, proposes activity levels resulting in maximum profits for each chain. As RME and ethanol chains compete for the same budget, when RME chain profits increase, ethanol chain decrease. Thus for each unitary tax exemption set the industry model can find many efficient solutions in the two-dimensional decision space of bio-fuel chains' profits that correspond to various activity levels. As a matter of fact the DM considers different sets of tax exemptions, and the bi-level model results in a large number of activity levels (conversion unit number and level of production for each chain). Then the multi-criteria model selects among all candidate solutions (activity levels) the best compromise that satisfies DM's objectives. This situation reflects real decision making regarding bio-fuels as, actually, French government decides about tax exemption levels but also it allocates permits of production levels to bio-fuel industry to build new or to expand existing conversion capacity.

Figure 10. Multi-level model flowchart



**energy crop market, supply curves in appendix B.*

Appendix D

Multi-criteria optimisation algorithm: Reference point approach

Optimisation of the scalarising function derived from the weighted Tchebychev norm:

$$s\left(z,\bar{z}\right)=\max_{h=1\ldots p}\left\{\lambda_h\left(\bar{z}_h-z_h\right)\right\}$$

with $$\lambda_h=\frac{1}{\left(z^*_h-n_h\right)}$$

and	$\bar{z}$	reference point representing aspiration levels
	p	number of criteria (objectives)
	z^*_h	maximum value on criterion h (ideal point)
	n_h	minimum value on criterion h, over the efficient set of solutions (nadir point)

Table 12. Pay-off matrix with multiple optima

Criterion optimised	surp agr	surp est	surp eth	subvention	CO2 sav
	M FF	M FF	M FF	M FF	Mt CO_{2eq}
surplus agriculture	**150,78**	194,33	27,13	1192,98	0,909
	150,78	194,33	32,60	1200,00	0,903
	150,78	188,61	36,42	1200,00	0,902
	150,78	177,69	43,71	1200,00	0,899
	150,78	220,41	0,10	1200,00	0,894
surplus esters	73,51	**248,80**	25,35	1187,10	0,733
	73,51	**248,80**	35,26	1200,00	0,722
surplus ethanol	56,86	11,49	**403,10**	1179,80	0,600
	56,86	25,78	**403,10**	1200,00	0,593
subsidies	44,84	40,97	12,65	**497,15**	0,376
CO_2 savings	150,79	194,33	27,13	1192,98	**0,909**
extreme value vectors					
Ideal point	150.79	248.80	403.10	497.16	0.909
Nadir point	32.51	5.04	0.10	1200.00	0.376

Table 13. Aiming at reduced public expenditures* and at higher environmental targets.

	Units	aspiration level	projection	aspiration level	reservation level	projection
surplus agr	MFF	112	57	112	32.51	112
surplus ester	MFF	167	118	167	5.04	167
surplus eth	MFF	93	6	93	0.10	32
budget (min)	MFF	497	657	497	1200	1044
CO_2 savings	tCO_{2eq}	0.655	0.556	0.908	0.700	0.714

* no reservation level